LEFTHANDEDNESS

A NEW INTERPRETATION

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LEFTHANDEDNESS

A New Interpretation

BY

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Foreword by

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"It is by the superior skill of his right hand that man has gotten himself the victory."

SIR JAMES CRICHTON-BROWNE.

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FOREWORD

THE phenomenon of bilateral manual asymmetry is of such universal interest and importance that any new light on its cause or significance is extremely welcome. This latest book on the subject, the product of a rigid scientific procedure, presents a novel method for the detection of the condition of left-handedness, and takes us a considerable step forward in our understanding and control of this age-long enigma.

The lefthanded have long been, and still are, viewed variously with veneration, awe, dubiety and distrust. Victor Hugo in "Les Miserables" has Jean Valjean say, "The lefthanded are precious; they take places which are inconvenient for the rest." Our national game of baseball sets a premium upon "portsided" pitchers and batters. On the other hand, lefthandedness is commonly associated with abnormality, physical and mental defect, ill omen, and things accounted "sinister." The universal feeling of the more favorable nature of righthandedness has crystallized in the word "dexterity."

The origin of the faculty of handedness is hidden in the mists of our prehuman ancestry. Racial and individual history conspire to suggest that the primal

state was one of ambidexterity. From such state humans became either decidedly lefthanded, or decidedly righthanded, or of lesser degrees of intermediate handedness. Speculation associates the initial bias with the earliest attempts to protect the more vulnerable left side of the body—the heart side—in manual combat. Whatever the origin of preponderant righthandedness, the ideas of right and left handedness became early associated with religious portents and ceremonies.

Handedness is simply one aspect of the detailed asymmetry of the body, anatomic and functional. The righthanded individual is almost invariably also right-legged, and possesses greater acuity of sight and hearing on the right side. The lefthanded individual is characterized generally by the reverse condition. Leftsidedness and rightsidedness are very fundamental conditions. For example, the frog tadpole almost invariably erupts its left forelimb before the right. The anomaly of "hare lip" is much more frequent on the left side.

Whether righteyedness follows rightsidedness, or whether rightsidedness follows righteyedness, or whether both are only related parts of the same larger aspect of sidedness, the whole dependent upon an unknown more fundamental condition, the "manuscope" invented by the author of the present work and herein described at length, gives us a readily ap-

plied and apparently unfailing method of detecting native lefthandedness. In view of the probable causal relationship between forced alteration of decided native bias towards lefthandedness and certain nervous conditions and speech defects, this instrument will furnish invaluable aid in the rational choice and application of therapeutic measures. Mr. Parson's work gives promise of helping us well past the barrier erected by von Bardeleben in his recent pronouncement: "We know as little why we are right-handed, and why a certain proportion of mankind are left-handed, as we are able to state what 'right' and 'left' are, or why there are dextro-rotary and levo-rotary solutions of sugar and other substances, or why some of the planets rotate on their axes from right to left and others in the opposite direction."

The present work indicates a new method of attack. Its originality inheres in the discovery of the phenomenon of "unilateral sighting" in binocular vision and in the demonstration of a definite correlation, possibly causal, between the dominant eye and the favored hand. Enlargement of view, novel approach, wider correlations—all these are here supplied. Such are the requisites for continued rapid advances.

H. E. Jordan.

University of Virginia,
January 12, 1924

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CHAPTER I

PRINCIPAL THEORIES IN REGARD TO HANDEDNESS

Despite a large number of contributions that fall strictly under the head of ephemera, the literature growing out of attempts to solve the mystery of right- and lefthandedness is extensive and interesting. We can say this even though we agree that much of it, in view of recent progress in physiology and psychology, will strike the scientific investigator as lacking in plausibility. Some of it, written in the sensational manner of the Sunday "feature" hack, can only be classed as interesting nonsense. On the other hand, here and there throughout the extensive desert of argument and discredited theory are great oases of truth. The purpose of the present writer is to review in outline the principal ideas already advanced, and to follow this by presenting in concise form a theory and demonstration that seem conclusively to account for all the various phenomena involved.

It will not be amiss at the outset to recognize two general classes of "handedness"—using this rather awkward word as a generic term to include right-handedness and lefthandedness. There is first of all a handedness that is native or natural, arising directly out of physical tendencies that are unmistakably congenital. Secondly, there is a handedness that is acquired in violation of the congenital trend, either through corrective educational measures, or as a result of bodily injury or disease. No other kinds of handedness exist. Ambidexterity should be looked upon not as a type of handedness, but rather as a condition in which the manual bias is entirely absent.

The principal theories advanced to account for the phenomenon of handedness may be classified roughly under the following heads:

1. Habit.
2. Hereditary Transmission.
3. Nursing and Early Education.
4. Visceral Distribution and Displacement of Center of Gravity.
5. Primitive Warfare.
6. Inequality of Blood Supply of the Brain.
7. Origin of Subclavian Arteries.
8. Superior Development of One Cerebral Hemisphere.
9. Ocular Dominance.

In this or in any other classification it will be found that the lines of demarcation are not always sharply drawn, as, for instance, between the theory which deals with the blood supply of the brain and that which has to do with the superior development of one cerebral hemisphere. In briefly outlining these theories no attempt will be made to enter into minute details or to discuss extensively the relative merits of the various ideas. The only purpose of the review is to acquaint the reader very briefly with the leading lines of thought on the subject of handedness.

HABIT THEORY

That handedness is the result of mere habit is the view most commonly held. Whenever the question is raised as to whether it is a congenital or an acquired characteristic it seems less difficult to account for it on the latter than on the former supposition, since if it were congenital there would apparently be required some predisposing anatomical reason for it, and this has never yet been successfully advanced. Sir Thomas Browne, in his "Vulgar Errors," declared that handedness is "the result of institution and not of nature;" and two centuries later Dr. G. M. Humphry, of Cambridge University, expressed the opinion that "there is no anatomical reason for it with which we are acquainted."

Professor Andrew Buchanan, of Glasgow, to whom we shall refer again, stated that "the preferential use of the right hand is not a congenital, but an acquired, attribute of man." Dr. G. M. Kellogg, writing in the *Journal of the American Medical Association* for 1908, believed that it was due to habit and training. Dr. Thomas Dwight, in *Scribner's* (April, 1891), observed that all attempts to account for handedness by purely mechanical theories have failed completely. Bardeleben stated in 1909 that no satisfactory anatomical explanation had as yet been made. Sir John Struthers, who has also written on the subject, expressed the opinion that "It has ceased to attract the notice of physiologists only because it has baffled satisfactory explanation."

Professor John B. Watson, of Johns Hopkins University, conducted a number of experiments with infants to determine "whether handedness is an instinct or a socially acquired habit." The results as given in his "Psychology from the Standpoint of a Behaviorist" are admittedly inconclusive, so that, in his own language, "we are left without conclusions as to the problem of handedness." Dr. Geo. T. Stevens, writing in the *New York Medical Journal* for August 17, 1918, stated his belief that handedness is the result of education and parental example.

These and similar views expressed by men whose names command attention have doubtless had a

tendency to discourage investigation, and to confirm the widespread belief that handedness is acquired as the result of mere habit, haphazardly begun and aimlessly continued until it becomes more or less firmly fixed. The great number of persons holding this view—and the number includes many instructors in primary schools, authorities on penmanship, and others whose work concerns the education and training of children,—argue that since handedness is thus so loosely and arbitrarily acquired, at no time is it a very difficult or momentous matter to change the habitual manual usage. Concerning the wisdom or folly of this attitude we shall have something to say later on.

HEREDITY THEORY

While the question of whether or not handedness is hereditary has little or nothing to do with its cause or origin, a number of authorities have confined their investigations to this one phase of the problem and have cited many cases to show that handedness is an inherited characteristic of the race. This, of course, is most convincingly shown in the case of lefthanded persons, who, as it were, furnish the exceptions that are used to prove the rule.

Dr. D. J. Cunningham, in "Right-handedness and Left-brainedness," the Huxley Memorial Lecture for

1902, supported the heredity theory and gave some examples to show that lefthandedness is transmitted from parents to children. Sir Daniel Wilson cited a number of similar instances. Weber, Merkel, Sawyer, and Bardeleben all believed that it is hereditary. Baldwin's experiments with his own child led him to the same conclusion.

Dr. H. E. Jordan, of the University of Virginia, who studied handedness in nearly 3000 individuals, representing 78 lineages, came to the conclusion that lefthandedness is hereditary, but "in what way or by what principle this inheritance acts remains obscure." After further research he finally demonstrated that it "follows very closely the Mendelian law of inheritance."

Professor Francis Ramaley, of the University of Colorado, made a study of the inheritance of lefthandedness in 305 families, containing 1740 persons, as a result of which Jordan's findings were strongly corroborated. Ramaley suggested that sinistrality may appear in families which have been without lefthanded ancestors for a number of generations.

The point has frequently been made that if heredity is really at work in the matter of handedness it must be working in accordance with some unknown law. Thus, Dr. William Ogle, after a series of painstaking investigations, conducted many years

ago, concluded that the appearance of lefthandedness is sporadic and "resembles abnormalities of bodily structure in its running in families."

Jackson sums up the arguments of a good many writers when he says, speaking of the inheritance of lefthandedness: "Surely, if heredity were a determining factor in the product, these constant and numerous violations of the law could not occur. There might be occasional deviations from the parent type, but they would be conspicuous by their infrequency, and not as at present by their great predominance; and, lastly, cases of prolonged hereditary descent or of a series of lefthanded generations in any one family are so extremely rare as to be practically unknown, whilst, according to the theory, they ought to be just as prevalent and familiar."

The investigations of Jordan, Ramaley, Hurst, Stier, and others sufficiently refute this sort of argument and demonstrate, as Jordan puts it, "the general validity of Mendelian law in the inheritance of lefthandedness."

Later on, in connection with our own experiments, we shall have something further to say about the inheritance of handedness.

NURSING AND EARLY EDUCATION

Beginning with Plato, a number of writers have advanced the idea that handedness is the result of

nursing and early education. We are told that the position of the infant in arms, its one hand restrained and the other free to exercise and develop, frequently determines whether it shall show lifelong preference for the right or left hand. It is further claimed that righthanded parents wittingly or unwittingly train the infant to dextral usage, and that this training becomes stricter as the child begins the use of spoon, knife, fork, pencil, etc.

In Professor J. M. Baldwin's tests with his own child, extending from the fifth to the ninth month of her life, he aimed to eliminate as far as possible the element of suggestion, in order to determine whether or not handedness would develop spontaneously. He reports that there were signs of righthandedness in the sixth and seventh months and a "distinct preference" shown in the seventh and eighth months.

Mrs. Helen T. Woolley conducted a somewhat similar test, obtaining practically the same result. She concluded that "righthandedness is a normal part of physiological development, not a phenomenon explicable by training."

Both of these tests would seem to discredit the theory that handedness develops as a result of early outside influences upon the infant. Objection may be made to the tests on the ground that they deal

with isolated cases and do not furnish sufficient data for generalizations.

Sir Daniel Wilson, as scholarly a writer as any who has dealt with the subject, came to the conclusion that "with the great majority, righthandedness is largely the result of education." Galippe and Broca held the same view.

VISCERAL DISTRIBUTION AND DISPLACEMENT OF CENTER OF GRAVITY

This theory rests upon the fact that the viscera are unequally distributed throughout the thorax, a condition that has been known and commented upon for a hundred years. A number of writers have urged it as a possible explanation of the mystery of handedness. In 1862 Dr. Andrew Buchanan, in a paper read before the Philosophical Society of Glasgow, advanced the theory anew, with some slight variations. He suggested, to put it briefly, that righthandedness is caused by a shifting of the center of gravity of the body toward the right, due to the greater weight of the liver and lungs on that side. Pointing out that the right lung has three lobes, while the left has but two, he claimed that as a result of the inspiration which precedes muscular effort the liver, and of course the center of gravity, is still farther inclined to the right. This, he thought,

would give the limbs on the right side of the body a mechanical advantage over those on the left.

In the following year Sir John Struthers published in the *Edinburgh Medical Journal* the results of his inquiry into the relative weight of the viscera on the two sides of the body. He found an inequality which causes the center of gravity to be displaced three-tenths of an inch to the right of the median plane, and this, he thought, accounted for handedness. The basic contention here is that a shifting of the center of gravity toward the right brings a greater weight on the right leg and foot, and so gives a firmer support for movements of the right arm and hand.

While the theories of these two writers are not identical, they are both founded on the same premises and are therefore sufficiently alike to be considered together. If what they propounded were true, we should expect to find cases of transposed viscera characterized by lefthandedness, whereas we find nothing of the sort. Neither do we find that lefthanded persons have displacement of the viscera. Furthermore, it has been pointed out by Dr. Cunningham that in the anthropoid apes "the viscera are disposed in a manner very similar to that characteristic of man. The center of gravity also lies to the right of the mesial plane,"—and yet we do

not find the slightest traces of handedness among these higher apes.

PRIMITIVE WARFARE

Dr. Philip Henry Pye-Smith, of London, writing in 1871, was apparently the first to suggest that man's employment of the club or spear originally led to a general preference for the right hand. Others have advanced the same reason. Thomas Carlyle, afflicted in his latter days with palsy of the dextral member, expressed virtually the same idea when, on June 15, 1871, he wrote in his diary that the origin of righthandedness "probably arose in fighting; most important to protect your heart and its adjacencies, and to carry the shield on that hand," wherefore, by inference, the other hand (the right) became the spear hand.

Dr. Geo. M. Kellogg, writing in the *Journal of the American Medical Association* for February 12, 1898, advanced the theory anew.

Sir James Sawyer in 1900 made almost the same suggestion:—"In the earlier days of the human race, when 'those may take who have the power, and those may keep who can,' we were a fighting people, a people fighting hand to hand. In such fighting a weapon such as a stick or sword was used. It is an advantage in so fighting to fight with a stick or with a sword which can be used by one arm and hand

only, the other arm and hand being used for balance, for defensive covering, or for offensive seizing. The right hand is preferred for the wielding of the stick or sword, so that the heart may be kept away, as far as possible, from the assault of the adversary. So arising, righthandedness would thence be transmitted by imitation, and by hereditary transmission of an acquired peculiarity."

Dr. G. M. Gould, in his "Righthandedness and Lefthandedness," published in 1908, adopts the primitive warfare theory when he says, "The first differentiation of function in the use of the hands doubtless arose in telling off the left hand and arm to hold the shield which should protect the heart side of the body from the adversary's blows."

Later on we shall deal at somewhat greater length with this theory of primitive warfare.

BLOOD SUPPLY OF THE BRAIN

Some authorities, including Judd, Lueddeckens, and Lombroso, have contended that the blood supply of the cerebral hemispheres is unequal, owing to an asymmetrical arterial system; and that handedness depends upon which hemisphere receives the greater supply.

Dr. W. C. Cahall has announced that righthandedness is due to the manner of origin of the right

and left common carotid arteries. "The carotid artery," he explained, "is a branch of the innominate artery on the right side, while it springs direct from the aorta on the left. This directness of communication, in addition to a larger calibre of the left carotid, gives the left hemisphere a decided advantage in the race of development."

Dr. Joseph T. O'Connor, writing in *Science* for December 12, 1890, advanced the same opinion. He thought that righthandedness resulted from a better blood supply to the left cerebral hemisphere because of the much straighter course taken by the great arterial channels.

Objection has been made to the theory on the ground that a reversal of the normal arching of the aorta does not cause lefthandedness. It has also been pointed out that the anterior communicating artery of the brain, as part of the *circle of Willis,* serves effectually to equalize the blood supply in the two hemispheres. The theory was further discredited when Dr. Cunningham measured a number of right and left carotids and failed to find the alleged difference in calibre insisted upon by Dr. Cahall. Crichton-Browne's measurements of rings cut from the carotid arteries within the skull also showed that handedness cannot be connected with cerebral circulation.

ORIGIN OF SUBCLAVIAN ARTERIES

In 1860 Dr. Hyrtl, of Vienna, in his handbook of anatomy, advanced the theory that handedness depended upon the origin of the subclavian arteries. He claimed that ordinarily we find a greater pressure of blood in the right subclavian artery, and, consequently, righthandedness; but that whenever the left subclavian had its origin *before* the right it would be found that the left side of the body was the better nourished and that lefthandedness naturally resulted.

This theory seems to have attracted an amount of attention out of all proportion to its merits, owing to the eminence of its proponent, one of the leading anatomists of his day. While the theory is a plausible one, it is by no means borne out by observation and ascertained fact. In the last analysis it is but another case in which a reversal of the viscera is unaccompanied by a reversal of handedness.

SUPERIOR DEVELOPMENT OF ONE CEREBRAL HEMISPHERE

Dr. Cunningham was one of the leading advocates of this theory, and his prominence as the Huxley Memorial Lecturer at the time his views were enunciated (1902) gave wide currency to the ideas he so ably championed.

His contention was that "righthandedness is due to a transmitted functional pre-eminence of the left-brain," and that it "has been attained in the ordinary course of the evolution of man by the subtle process of Natural Selection."

Dr. Ogle, expressing much the same view, believed that "righthandedness depends on some predominance of the left brain, and that lefthandedness, when it occurs, depends on a transposition of this structural peculiarity, whatever it may be."

Professor Baldwin, as a result of the experiments already alluded to, reached the conclusion that righthandedness "is due to a difference in the hemispheres of the brain reached at an early stage of life."

Gratiolet believed that it depends on the early fœtal development of the anterior and middle lobes of the brain on the left side, furnishing an increased supply of nervous energy to the right side of the body.

Jordan arrived at practically the same conclusion. "The fundamental anatomic variation," he says, in his *Hereditary Lefthandedness,* "presumably inheres in a fœtal asymmetry of the cerebral blood supply, producing probably an unequal development (microscopic) of the hemispheres."

Crichton-Browne thought that asymmetry of manual function results directly from asymmetry of

convolutional development in the two hemispheres.

LeConte, without attempting a detailed explanation, simply expressed the opinion that "People are righthanded because they are left brained."

Nothing is to be gained by multiplying these citations, all of which have practically the same tenor. It is enough to say that many attempts have been made to show that the cerebral hemisphere which innervates motor activity on the preferred side is characterized by some structural superiority, involving a difference in weight or cortical area. These attempts have given contradictory results, leaving the unavoidable inference that the superiority which is so generally recognized is purely functional, and is unaccompanied by discernible structural peculiarities.

OCULAR DOMINANCE

In his Cambridge lectures published in 1861 under the title, "The Human Foot and the Human Hand," Dr. G. M. Humphry briefly referred to a correspondence of function between hand and eye. So far as can be traced this is the first recorded mention of the idea that was to grow into the theory of ocular dominance.

In 1881 Professor Joseph LeConte, in his excellent work, "Sight," called attention to the same idea,

stating that "people are right-eyed as well as right-handed, and left-eyed as well as left-handed."

Dr. Peter N. Callan, of New York, writing in the *Medical Record* for April 2, 1881, dealt briefly with this same theme under the caption, "Are We Right-eyed?"

On April 17, 1904, Dr. Austin Flint published an article in the New York *Sun* in which he said, "The normal man not only is right handed, but he uses the right leg and the right eye in preference to the left."

In August, 1904, Dr. George M. Gould, of Philadelphia, published an article in *Popular Science Monthly* in which the theory was further developed. Dr. Gould subsequently published other papers dealing with the subject, and in 1908 collected these in a volume entitled "Righthandedness and Lefthandedness," in which the theory of ocular dominance was dealt with at length.

According to this theory, handedness "depends upon which is the better seeing eye." Gould claimed that in about 96 per cent. of infants the right is the better eye, "and thus compels the right hand to work with it."

In *Science* for August 6, 1909, there appeared a review and criticism of Gould's book by Professor H. C. Stevens, of the University of Washington, in which several objections were taken to the theory,

the chief one being as follows. We quote Professor Stevens:

"In binocular vision it is impossible to distinguish the field of vision of one eye from that of the other. To all intents and purposes the two eyes function as one. Even if the right eye, for example, were vastly worse than its mate, the right half of the field of vision would not be less clear than the opposite half. The whole field would suffer a uniformly distributed defect; but, unless some special test were made, the patient would be entirely ignorant of the fact that his right and not his left eye was defective. With a uniformly dim, or a uniformly clear, field of vision, where is there any motive in vision to the use of one, rather than the other, side of the body?"

Apparently no one was able to answer the question, for in 1911 Dr. Jordan, writing in the *American Breeders' Magazine* on "The Inheritance of Lefthandedness," made use of the following language:

"The more recent theory of Gould to the effect that righthandedness follows the generally more perfect development of the right eye, advanced to supplant all former theories, has been shown by Stevens to be of doubtful verity. It seems more nearly correct to think of right-eyedness as a condition concomitant with righthandedness and both dependent upon the same or related cause. At any rate the offered proof is not compelling that they are related

as cause and effect. And until Gould shall have frankly reckoned with, and satisfactorily met, Stevens' criticism his 'theory' remains largely a speculation."

Dr. P. Fridenberg (see bibliography) has also been a rather severe critic of the "ocular dominance" theory as advanced by Gould.

The above are the principal theories of handedness. There are others, but in the opinion of the author they are of little interest, and of even less importance. Bardeleben, writing in 1909, concluded that there was as yet no solution of the mystery, but consoled himself with the philosophic reflection that "no solution was better than one or several that are erroneous."

CHAPTER II

BRAIN AND HAND

It has long been known that dextrality (and, of course, sinistrality) affects not only the hand and arm, but also the whole side of the body, due to the greater activity of the cerebral hemisphere which governs the favored side,—the right hemisphere in the case of lefthanded persons, the left in the case of righthanded. Van Biervliet's experiments [1] in 1897 showed that handedness is usually accompanied by a corresponding keenness of the optic, acoustic, tactile, olfactory, and gustatory motor nerves on the dominant side of the body; and we are usually rightfooted as well as righthanded, though not always in the same marked degree.

Bilateralism is, of course, an inheritance that comes to us from lower biologic forms, in many of which it is more positive than in the case of man. Especially is this true of organisms not possessed of binocular vision; here the eyes are so far to the side and the visual axes so divergent that there can be no common field of view; each eye therefore guards

[1] J. van Biervliet, *L'asymétrie sensorielle* (see bibliography).

and exercises dominion over its own particular side of the body, resulting in an independence of movement and function that is striking.

In the human organism with its double nervous system we find traces of this same independence of function, although on account of binocular vision and a common field of regard there is a more complete coördination of sight impulses and impressions. But, as we shall see, it is bilateralism none the less, —the same divided brain, the same anatomical duplications, and above all the same dependence of movement upon vision that we find in the lower forms.

This dependence of movement upon vision needs to be emphasized, since it is the real key to the secret of handedness.

It would be no exaggeration to say that in infancy nearly all voluntary movement depends upon vision. There is, of course, some movement stimulated by auditory, tactile, and other sense impressions; and even from birth there is probably some volitional muscular effort exerted independently of any direct influences from without; but in a normal child it will be obvious to the most casual observer that by far the greatest stimulus to movement is vision. This, indeed, in a broad way is true also of the adult and continues true throughout life.

Remembering now that handedness is accom-

panied by a corresponding keenness of sense impressions on the favored side, particularly by superior acuity of sight, we become aware of a limited but suggestive parallelism to the case of the lower forms already alluded to,—forms in which the right eye governs the movements of the limbs on the right side, and the left eye the movements of the limbs on the left side of the body. This ancient harmony of function survives in man at least to the extent that righteyedness accompanies righthandedness, and lefteyedness accompanies lefthandedness, all this notwithstanding man's possession of binocular vision.

With these facts in mind we are prepared to learn from pathology that the all-important motor centers for the hand and arm and for some of the more expert visual operations (to be afterwards explained) on the preferred side lie close together in the left cerebral hemisphere for the righthanded, and in the right hemisphere for the lefthanded. We have only to picture the divided cerebrum, with its great longitudinal fissure, to understand the advantage accruing to these closely related centers from the fact that they occupy contiguous areas in the same hemisphere.

Now, in addition to the duplicate faculties which characterize all bilateral forms, man has developed certain dominant *single* faculties, such as speech and

memory, which cannot be classed as belonging to either side of the body exclusively, but rather to the organism as a whole. In a general way it can be stated that we find the neural areas which innervate these highly complex single faculties *grouped in the same hemisphere that contains the centers controlling handedness and eyedness.*[1] This close associative arrangement, it need scarcely be pointed out, affords the most direct and speedy coordination of sight impressions with intellect, will, and action.

The fact that the left brain controls, through a decussating nervous system, the right side of the body, and that the right brain in like fashion governs the left side, is abundantly confirmed by pathology. And while the structure of the two brains is apparently similar, save only for some asymmetry of convolutional arrangement, with no appreciable difference in size, weight, or cortical area, at the same time a functional difference causes one hemisphere to be incomparably the more active,—to be, in short,

[1] The topography of the cerebral visual areas remains somewhat obscure. At least some of the macular fibers of each eye are connected with both hemispheres. It may be said of the optic nervous apparatus generally that the crossed fibers probably represent the primitive connection, while the uncrossed represent a diversion necessary to the development of binocular vision. That there are certain important visual operations in which the sense-perception is entirely unilateral will be demonstrated later. It is to these monocular operations that the word "eyedness" has reference.

the chief seat and generator of speech (written and articulate), of handedness, eyedness, memory, volition, and other psychic activities that go to comprise intelligence and personality.

Pathology demonstrates all this in a hundred illuminating ways. For instance, in the case of a righthanded adult, injury to the motor speech areas in the dominant left hemisphere will cause a loss of the power of articulation, while a similar injury to the corresponding center in the right hemisphere will result in but a slight temporary awkwardness of speech. The reverse is, of course, true for left-handed adults. In the case of young children an injury to the speech areas of the dominant hemisphere seldom causes permanent loss or impairment of speech, for the reason that the other half-brain usually assumes and develops the lost function. This wonderful cerebral adaptability, though quite marked in childhood, later in life almost entirely disappears.

We have further pathological demonstrations of the fact that eyedness, handedness, speech, and writing are controlled from contiguous areas in the same half of the brain. Thus, for example, the same injury may produce aphasia and agraphia, showing the proximity of the centers for utterance and writing. Again, impairment of speech almost invariably accompanies paralysis of the limbs on the favored

side, provided, of course, the paralysis has its origin in the cerebrum, and not peripherally,—a pathological demonstration of the close relationship of speech and handedness. Broca long since located the speech center in the third frontal convolution. Adjoining it is the area for hand movements, while that for movements of the eyes lies just behind the prefrontal lobe. The interdependence of these functions is beautifully shown, as Baldwin has pointed out, by the fact that the favored hand is used for expression *even before the beginning of speech;* he concluded that "speech has arisen from the setting aside for further development of the area in the brain first used for the right hand." [1] That sign-language preceded vocal speech has long been suspected. Of further significance in the study of these closely coördinated faculties is the fact that the congenitally blind show little native tendency to handedness, thus negatively confirming the dependence of handedness upon vision.

As this is being written the morning's paper brings news that the premier of one of the great European states has been stricken with apoplexy, affecting his limbs on the right side. We quite naturally wonder how seriously the patient, if he lives,

[1] Flint (see bibliography) instances a curious fact in this connection. "It has lately been observed," he says, "that deaf mutes may have an aphasia that prevents the use of the right hand in the sign language."

will be handicapped by his paralysis. There is nothing in the first despatches to give a clue; but the afternoon papers say that in addition to paralysis of the right hand, arm, and leg, there is also a serious impairment of speech. Now, because speech and movements of the dominant hand are both innervated from the same cerebral hemisphere, these later despatches in effect inform us that the premier is righthanded, and that his future usefulness is all the more seriously menaced because of the fact that the stroke affected the dominant side of his brain, and therefore the dominant side of his body. In this case, as in the case of all righthanded persons, left hemiplegia would have been much less severe.

We have already spoken of the great advantage arising from the fact that the neural centers of the principal faculties are all grouped in one side of the brain. This advantage will be fully understood if we remember that the two halves of the brain are so nearly independent that were the active innervating areas located indiscriminately in *both* hemispheres, then coördination of the various stimuli and impulses leading to thought and action could take place only after there had been communication back and forth between the two halves. In this case the connecting nerve tissues, or commissural fibers, which form the lines of communication between the hemispheres, would furnish the means of coördina-

tion. That this complicated arrangement, as compared with the normal grouping of the principal centers in one hemisphere, would be less direct and therefore less efficient, and that to some extent it would make for delay and indecision, is self-evident. Indeed, some authorities claim that occasional cases of stammering can be traced directly to forced transfers of handedness,—forced either as the result of injury to the favored hand, or as the result of corrective educational training.

This question—the relationship of impaired speech and reversed handedness—is a much disputed one. In the opinion of the present writer, based on extensive observation, the danger of any such result in the case of young children is so slight as to be negligible. Later in life the matter presents a different aspect: the cerebral processes have then become fixed; neural and muscular coördinations have become more and more automatic; the various functions of the somatic mechanism have become thoroughly adjusted and stabilized. In this condition any radical innovation such as a change of handedness comes in the nature of a calamity. The admirable grouping of the centers in one hemisphere is broken up, and the activity of some of them (chiefly the areas for handedness and writing) is transferred to corresponding locations in the opposite hemisphere. In the case of persons well along

in life this not infrequently results in some more or less serious morbidity of nervous function, manifested either in chronic indecision, stuttering, amnesia, agraphia, or some other disorder indicative of confusion in the cerebral processes.

These rather elementary truths must be borne in mind if we are to grasp the real significance of the phenomenon of handedness. In connection with them it now becomes necessary to explain in the most general way some of the basic facts relating to vision, with especial reference to double images. Without an understanding of these fundamentals the relationship of vision and handedness will not be apparent.

CHAPTER III

HETERONYMOUS AND HOMONYMOUS IMAGES

Of the five senses, three—touch, taste, and smell, —become manifested through direct contact with the object or substance sensed, whereas the two higher perceptive faculties, hearing and sight, result from vibratory stimuli transmitted by the air and ether. In the study of handedness we are concerned principally with the most elaborate of all the sense organs—the eye. For the purposes of this exposition it will not be necessary to enter into a detailed description of it, or of the optic nervous system; it is important, however, that we point out some of the differences between monocular and binocular vision.

From a purely physiological standpoint monocular vision is a comparatively simple process, there being but two possible adjustments of the single eye —the focal, in which the ciliary muscle adjusts the optic lens so as to throw a perfect image on the retina, and secondly, the adjustment of the pupil to regulate the amount of light. The process in some respects resembles the working of a photographic

camera; in both cases there is a lens, a shutter, a focussing apparatus, and a sensitive substance which receives the image. The chief difference lies in the method of focussing: in the camera a sharp image is obtained by regulating the distance between lens and sensitized plate; in the eye the same result is brought about by a change in the convexity of the lens, effected automatically by the ciliary muscle when we look at anything. The action of the shutter in the camera is of course paralleled in the case of the eye by the dilation and contraction of the pupil.

In addition to these two adjustments necessary to the formation of distinct monocular images, there is a motor apparatus which affords the eye a wide range of movement, laterally and vertically, and enables it to bring into the line of sight any object lying within the visual field. By the line of sight is meant the imaginary straight line passing from the point of regard through the nodal point of the lens to the most sensitive part of the retina, known as the *fovea centralis* (central pit) of the *macula lutea* (yellow spot). This supersensitive area is about one twenty-fifth of an inch in diameter, is situated in the axis of the eye, and forms, as we have said, one terminus of the visual line, or line of sight. The other terminus is the object or point looked at—the point of regard, or, as it is sometimes called, the

point of fixation. Distinct vision is limited to this point and a very restricted area immediately around it.

In binocular vision the adjustments are vastly more complicated, as are the psychic elements involved.

Binocular vision results when the eyes are so turned by the recti muscles that the two lines of sight meet at the point of regard. What happens is that the separate and slightly dissimilar images of the two eyes are combined and fused into a single, lucid, undistorted picture. In ideal binocular vision there is always a shifting of images to the middle, so that the two eyes may be said to function as one; indeed, the term "Cyclopean eye" (*œil cyclopienne*) is used to describe a wholly imaginary eye, situated in the median plane, that registers the binocular image. This idea leads naturally to the further conception of a middle or binocular visual line, or line of sight. Of course there is no such thing, since there is no Cyclopean eye, but the idea has been found useful in explaining the theory of ideal binocular vision. That it does not explain ordinary everyday vision as most of us experience it is a matter that anyone can demonstrate for himself, as will be shown later on.

The great law back of all binocular phenomena is known as the law of corresponding points, accord-

ing to which single images are formed only when the light rays from an object, or from the various parts of an object, fall on corresponding points of the retinæ. With certain negligible exceptions, this can happen only when the object is situated at the point of regard. In other words, practically all objects lying within the binocular field of view, with the exception of objects situated at the point of regard, are seen double. If this seems a somewhat startling statement it is due to the fact that we are not as a rule given to close analysis of the most ordinary visual phenomena. Another reason is that double images are seen indirectly and therefore indistinctly, so that their duality is not obtrusive. A simple and well-known experiment will illustrate and confirm the truth of this statement:

Lengthwise on a piece of heavy cardboard 20 inches long by 5 inches wide draw a median pencil line, NE (Fig. 1), and at one end of this line cut a notch to fit the bridge of the nose, N. On either side of this notch indicate by pencil marks the position of the eyes, L and R, remembering that the average distance between centers of pupils is approximately 2⅝ inches. Next measure off along the median line, beginning at the nasal indentation, three points 6 inches apart, A, B, and C. From the marks which indicate the position of the pupils (L and R) now draw straight dotted lines to A, B,

and C, and also (parallel to the median line) two dotted lines, LD and RF. Finally, stick a pin upright into each of the three equidistant median points, A, B, and C.

Having done all this, now hold the cardboard to the eyes in such a way that the notch fits the bridge of the nose and the plane of the card lies slightly be-

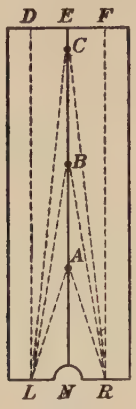

Fig. 1.

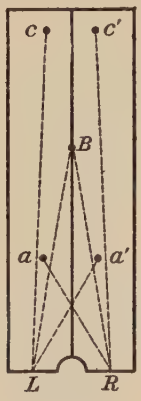

Fig. 2.

low the horizontal visual plane; the converging dotted lines will then represent the visual lines when the point of regard settles upon A, B, and C, while the lines LD and RF represent the lines of sight when the visual axes are parallel; in other words, when the gaze is directed toward infinity.

Now converge the visual axes upon B. The resultant images, belonging to the phenomena of pure

binocular vision, are shown in Figure 2. It will be observed that B, situated at the point of regard, is seen as a single image, while A and C are doubled, though in a different way, as is shown in the diagram. A, because it is nearer than the point of regard, is seen in crossed or heteronymous images, the left image (a) belonging to the right eye, and the

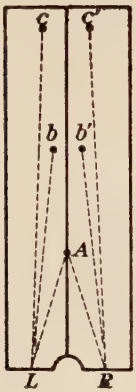

Fig. 3.

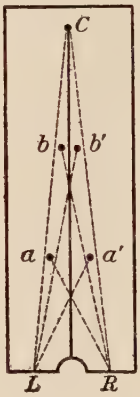

Fig. 4.

right image (a') to the left eye. C, on the contrary, while also seen as two images, is doubled homonymously, which is to say that the righthand image (c') belongs to the right eye, and the left image (c) to the left eye.

Figures 3 and 4 illustrate the remaining possibilities of this experiment. Figure 3 shows the result when the ocular axes are converged upon A. Here B and C are both doubled homonymously. On the

other hand when the eyes are focussed upon C, as in Figure 4, then A and B are seen in crossed or double heteronymous images, those at *a* and *b* belonging to the right eye, while those at *a'* and *b'* belong to the left eye.

This simple experiment, which is described in the works of nearly all writers on optics, as well as in the works of the principal authorities on psychology and physiology, epitomizes many important facts of pure binocular vision. By most writers it is given virtually as above, although we have improved somewhat on the usual diagrammatic representation of the resultant visual images.

The experiment impresses us with the apparent existence of a point of judgment or reference situated midway between the eyes, and seems amply to justify the conception of a Cyclopean eye and a median line of sight. We clearly perceive that double images occupy corresponding positions on either side of the median plane, and that when we combine them by proper adjustments of the ocular axes the position occupied by the resultant single images invariably lies in the median visual line, or Cyclopean line of sight. In other words, there is a shifting of images to the middle—a shifting that is apparently uniform, both in regard to speed and in the distance traveled by each image.

We shall deal further with this conception of the Cyclopean eye in the next chapter.

CHAPTER IV

UNILATERAL SIGHTING

It has already been explained that while man has a bilateral bodily structure in which there are many anatomical duplications, he also possesses certain single faculties characteristic of the organism as a whole, these latter for the most part being of a psychic nature. We thus class the ego, or self-consciousness, with cognition, memory, attention, judgment, volition, and other faculties and proclivities, mental and moral. Now, whether the ego has a definite circumscribed dwelling-place, and if so, in what part of the body it may lie; whether reason is definitely localized; whether the ancient Hebrews were right in ascribing affections to the heart, or the Greeks in thinking that the breast, or φρήν, harbored the emotions in general,—these and similar metaphysical speculations have, of course, no place in the present inquiry. And yet some light might be shed on the question of handedness if we could localize the orientating faculty, or at least the anatomical reference point which obviously must be employed by the ego in forming *judgments of direction.*

The search for this point of reference leads us at once to vision and to the eyes as the principal end-organs of the central mechanism of orientation. We realize, of course, that all the sensory nerves are able in some degree to contribute to our faculty of estimating direction, although the information furnished by hearing, touch, taste, and smell is not always reliable, vision alone supplying with reasonable exactness the geometrical data so necessary in determining the relative position of points in space. A little reflection will show us that in order to obtain for the central consciousness these geometrical data, the eyes must utilize some one fixed point of observation, some definite point of origin from which the optic surveys can be initiated.

It has long been held that this reference point lies in the median plane, in the position allocated to the imaginary Cyclopean eye, and our experiments in the last chapter would at first glance seem to bear out this contention. Let us look a little further into the matter.

The median eye is apparently the invention of Hering, who called it the "double eye." Helmholtz subsequently adopted the idea, but called the imaginary third eye the "Cyclopean eye," a happy expression that has been used ever since by all the chief authorities, including our own LeConte. These

three men—Hering, Helmholtz, and LeConte,—all possessed true binocular vision; a rather strange circumstance, since true or impartial binocular vision is comparatively rare, yet a fact easily deduced from their writings. And because they did possess true binocular vision the experiments above noted apparently satisfied their ideas as to all resultant possibilities in the matter of heteronymous and homonymous images. It might be well to see whether there are not some other possibilities that have been overlooked.

In order to do this let us put aside the apparatus used in the previous experiments and now boldly attempt to produce the same phenomena with the unaided eyes—in other words, under conditions such as obtain in actual everyday visual experience. Before we have proceeded very far we begin to realize that our piece of cardboard, with its indentation for the nose, its measured interocular space, its carefully drawn lines, its dots and pins, served most effectually to regulate and standardize the ocular processes, for without these guiding and regulatory aids the vast majority of us obtain a very different set of results indeed. The reason is that few of us possess pure binocular vision. One eye seems to do most of the work—to be the directing or controlling eye; whereas in true binocular vision—whether it be natural, or whether artificially produced, as in

the previous experiments,—the two eyes function impartially, neither one predominating.

So rare is this optic impartiality—so common is the singular *inequality* of ocular function—that most of us may be described either as righteyed or lefteyed, just as in manual facility and usage most of us are either righthanded or lefthanded. But in order to demonstrate all this, as well as to forward our search for the fixed anatomical reference point which would seem to be so necessary in forming accurate judgments of direction, we must have recourse to our second experiment, as follows:

Converge the ocular axes upon a point in the median plane and about five feet distant; then, with both eyes open, interpose a finger as nearly as possible in the median line of sight and about two feet from the eyes, so as to cover the distant point of fixation. According to the principles illustrated in Figure 2, the finger will be doubled heteronymously; but whereas in the previous experiment the heteronymous images appeared at equal distances on either side of the median plane, we now (if we are righteyed, as most of us are) see one of the images (the one belonging to the right eye) apparently on the median line of sight, while the other (the image belonging to the left eye) is at some distance to the right. A person trying this experiment for the first time would probably represent the result as in Figure

5, where L and R are the eyes, NP the median line of sight, P the point fixed, and *f* and *f'* the heteronymous images of the interposed finger.

Now, while this diagram is not wholly without plausibility and reason, it is nevertheless wrong, as we can readily enough prove by alternately closing the right and left eyes while the interposed finger is

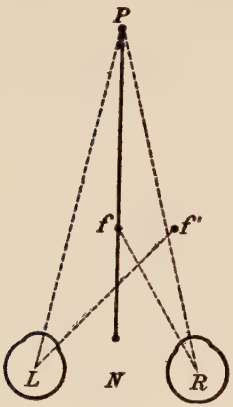

Fig. 5.

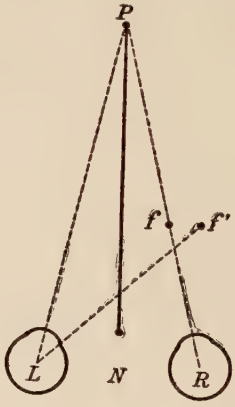

Fig. 6.

still directed toward the point of fixation. We learn in this way that a correct representation of the resultant heteronymous images would place them as in Figure 6, a diagram that is of peculiar significance in the explanation of handedness.

Careful study of the phenomena epitomized in Figure 6 reveals several arresting and important truths:

First, we perceive that despite our earnest endeavor to interpose the finger somewhere along the Cyclopean or median line of sight, we have actually (still supposing that we are righteyed) *interposed it along the line of sight of the right eye.* This is the most significant point involved in the experiment—a point that we should mentally underscore and never lose sight of throughout the following pages.

Secondly, if we slowly shift the gaze from the point P to the finger itself we note that the double images *f* and *f'* in the process of combining into a single image do not seek a midway fusion point, as was the case in our previous experiments with the cardboard, but that the image belonging to the right eye *remains stationary on the right visual line,* while that belonging to the left *travels the entire intervening distance* in order to unite with its fellow image.[1] It is evident that this is a radical departure from the phenomena studied in our first experiments. We saw in Figures 2, 3, and 4 that in impartial vision with two eyes double images invariably occupy false positions, yet here is a case, apparently similar, in which one of the double images successfully maintains the position of the single image. In other words, one of the heteronymous images, far from being false, is unmistakably a true

[1] Tscherning notes this phenomenon. See his *Physiologic Optics,* p. 309.

one. To express it still differently, the object at which we are gazing is seen in the same position whether we view it directly or indirectly.

Thirdly, we note the apparent unimportance and optical inferiority of the image belonging to the left eye. Compared with the image belonging to the right it is shadowy and unsubstantial, and while usually disregarded entirely it is sometimes in evidence, and at these times tends to confuse and hinder, rather than assist, the visual process. But so unobtrusive is this shadowy secondary image that some persons have difficulty in perceiving it at all.

A significant thing about this experiment is that the interposed finger may belong to either the right or left hand; or the procedure may be varied and the underlying principle emphasized by using the index fingers of both hands, joined at the tips so as to constitute a pointer. The results in any case will be found the same.

These deviations from standard or true binocular vision of the strictly impartial sort studied in our first experiments demonstrate conclusively that in several important respects unaided natural vision is bilaterally asymmetrical, and that in matters of exact orientation we are virtually one-eyed. In other words, for purposes of sighting or pointing we automatically and unconsciously disregard the median line of sight and use either the right or left visual

line, depending on whether we are righteyed or lefteyed. Stated succinctly, we may say that if we are righteyed, then in judging the position of objects seen indirectly we habitually disregard the median and left lines of sight and use only the right; if we are lefteyed we use the line of sight belonging to the left eye and disregard the other two.

A little reflection will enable us to understand just why we do this. In the first place the act of sighting or aiming requires that we bring into strict alignment three points—the center of the macula, the point of regard, and one other intervening point or object. But we have learned from our first experiments (see Figures 2, 3 and 4) that with impartial binocular vision it is impossible to bring two or more images into the median line of sight simultaneously. If we fix one we double the others, and no amount of practice or self-discipline will enable us to solve the difficulty, which in truth is insolvable.

But if sighting is an impossibility when the two eyes function together it becomes a simple matter for either eye separately. Monocular sighting is thus born of necessity to remedy an unavoidable defect in the wonderful binocular mechanism. That it characterizes not only man, but also all species that possess binocular vision is self-evident.

It thus appears that the only accurate judgments of direction that can be referred to the median or

Cyclopean eye are those which involve but a single position in space, this position in all cases being the point of fixation of the two eyes. As soon as other elements enter into the problem, binocular vision, handicapped by double images, is unable to function with any degree of accuracy and resigns the orientating office in favor of monocularity.

It might be well to add that while the process of unilateral sighting is, of course, strictly monocular, we are not to conceive of it as taking place while one eye remains closed; on the contrary our experiment demonstrates the facility with which we sight or aim while both eyes are open and functioning. What happens is that we use exclusively the data furnished by one eye, and automatically suppress or disregard the image supplied by the other.

CHAPTER V

HANDEDNESS

WITHOUT attempting to localize Mind or to identify it with Brain, most of us nevertheless instinctively feel that the faculty of vision—not the end-organs solely, but also the central organ of sense, —is seated in the cranium. We feel this, we believe it, we intuitively *know* it—quite independently of the vast weight of confirmatory evidence afforded by pathology.

We can go a step farther and say that while the psychology of vision is lamentably obscure, nothing seems more evident than that for most of our visual judgments the ego utilizes as a fixed point of reference the position assigned to the phantasmal Cyclopean eye. Included in this category are judgments of distance, form, size, solidity, texture, light, shade, color, motion, and some of the simpler conceptions of direction.

For accurate judgments of relative spatial position, and particularly for all sighting or aiming operations, we have seen that the Cyclopean eye will by no means serve as a proper reference base, owing to

the fact that the very nature of binocularity precludes the fixing of two points in the median line simultaneously. It will do no harm to stress this—to reiterate that the exact determination of direction frequently involves the bringing of two objects into line with some fixed somatic reference point; that in order to appear single, when seen binocularly, these separate objects must be situated at the point of regard; that when not so situated they appear double; and that since it is impossible to converge upon two points of regard at one and the same time, binocular vision, which so wonderfully records impressions of distance, depth, and three dimensional form, is unable to function with any degree of exactness when some of the essential sight-data are observed indirectly.

In order to remedy this innate and unavoidable fault in the binocular mechanism, nature has provided—perhaps has preserved from some of the lower forms—a species of monocular or linear vision whose province it is to register the impressions destined to be used by the central consciousness in estimating relative positions in space. This monocular orientating faculty is probably possessed in some degree by all creatures that have binocular vision. It has the peculiarity of being able to function while both eyes remain open, though in man we find that requirements of extraordinary exactitude occasion-

ally prompt the closing of the second eye, which for the moment becomes a hindrance rather than a help. In operations involving a lesser degree of exactness, which is to say in ordinary every-day vision, this closing of the second eye is unnecessary.

And now the somatic reference point for judgments of relative spatial position—the base from which the visual directions start—where and what is it? Those who have followed the various steps of this brief exposition will have little difficulty in deciding for themselves that it is the center of the macula—the point of keenest vision—of the sighting or orientating eye. It is from or through this point that the linear surveys are made—that sighting and aiming are achieved. Here, we are almost tempted to say, sits orientation itself, the direction-finding ego, the somatic geometer. Fechner, with his theory of the sentience of nerve-structure, might have said so. But there is no need to localize the faculty itself; the macula is at least its outpost, and for our purposes this knowledge suffices.

Having ended our search for this point of reference, let us now come to the real significance of these various matters in so far as they relate to our study of handedness.

It has been shown that owing to an inherent fault of binocular vision the aiming or sighting faculty functions as a result of sense-data secured through

unilateral, rather than bilateral, processes; that it acts monocularly from or through the macula of what we may call the pointing or compass eye; so that for accurate judgment of the position of objects seen indirectly most of us are in effect one-eyed. When logically interpreted these incontestable and easily demonstrated truths clear up the mystery of handedness.

Consciously or unconsciously we make use of this important monocular sighting faculty in all movement that is directed by vision; and this means in nearly every manual or digital act that involves pointing, reaching, touching, or grasping. Speaking in an optical sense, the object pointed at, grasped, reached for, or touched is the point of regard, constituting one end of the visual line whose other end is the center of the macula of the sighting eye, while the third factor is the active hand or finger, which, in order to operate with certainty and speed, must be brought into alignment with the other two positions. It is evident that while there are an infinite number of directions which the hand could follow in pointing at or moving toward an object, there is but one whose rectilinear course coincides with the absolute standard direction-line of the pointing or orientating eye. Whenever the hand is guided by vision this is the direction naturally and inevitably taken.

Nor, as we have seen, does it make any difference which hand is used; both will necessarily be guided by the visual line of the sighting eye, our second experiment having demonstrated that if (for example) we are righteyed, then the right visual line points the direction not only for the right hand, but for the left as well. All this will be better understood if we conceive of this "sighting" line as belonging not only to the eye and hand, but to the whole body—to the corporeal ego. If we are lefteyed, conditions will, of course, be reversed, and the left visual line becomes the organism's sighting line.

We can, therefore, use either hand, and both will follow the one visual line of direction. But which hand do we use most?

Whenever possible we use the one on the same side of the body as the sighting eye; this, from the ego's point of reference, being the *nearer* hand—the one we can more easily and quickly bring into position—the one that on account of our physical configuration we can *aim* more naturally and effectively. To use the other would mean that we deliberately select the hand that is farther away—the one that would take longer to get into action—that would have to act in a more strained and awkward position—that in every way would be less ready and less capable than the hand nearer the sighting eye. This will be plain enough if we remember that "sighting"

is (as we have remarked before) a species of monocular vision, even though we sight with both eyes open. In other words, it is a process in which one eye is inactive, or rather, in which the image of one eye is disregarded. If we close this eye and experiment in the matter of sighting by using the two hands alternately, their relative availability and efficiency will become more strikingly apparent. It will be found that the hand which is on the same side of the body as the sighting eye operates easily and naturally along the nearby line of sight, while the hand brought over from the side of the quiescent eye finds itself farther from its native lateral position, in a somewhat strange and anomalous zone of activity, and therefore operates at a marked disadvantage.

It is this difference in the distance each hand must travel in order to reach the visual line of the sighting eye when the head is in the primary position and the gaze directed forward that determines whether we shall use the right or the left hand. And the difference is a real and very appreciable one, amounting at the eyes to the full interocular space, although it diminishes as the point of fixation is approached. Now, if the Cyclopean eye really existed, so that we could sight from the median position, there would, of course, be no necessity for this choice of hands, since one hand could reach the sighting line as readily as the other,—a condition that would

tend to bring about universal ambidexterity. But the Cyclopean eye does not exist, although the fact that it does not is so frequently lost sight of that we are reminded of Bryant's observation in his *New System of Ancient Mythology,* to the effect that whilst we cannot believe the pagan fables, we forget ourselves continually and make inferences from them, as from existing realities.[1] Thus it has been with the writers on vision; they have given the fable of the Cyclopean eye a quasi-substantiality and a certain standing among scientific truths, whereas it is a serious question whether this fantastic conception has not befogged more optical truth than it has illumined.

Our investigation thus far demonstrates that handedness results from an innate fault or limitation of binocular vision, on account of which all sighting or aiming operations are necessarily carried on unilaterally. The whole matter hinges on our judgment of the direction of objects seen indirectly. This, in binocular vision, is merely approximate, while monocularly—from a fixed somatic reference point—it is absolute. It follows as a most obvious corollary that the hands, which are so dependent on vision for accurate movement, are forced to accommodate themselves to this radical deviation from

[1] *A New System, or an Analysis of Ancient Mythology,* by Jacob Bryant. London, T. Payne, 2d Edition, 1775, p. 453.

binocularity, and that one hand—the one nearer the sighting eye—is by every anatomical and physiological consideration invested with vastly more importance functionally than the hand which is farther away.

The point is likely to be made that by closing one eye we can sight perfectly well with the eye that remains open, irrespective of whether it is the right or left. This is conceded, although it does not affect the present argument. Each eye separately does give a true direction, but only one of these directions can be used when both eyes are open and functioning. We are to understand that the ego, or conscious intelligence, or perhaps we should say the attention,—a single entity,—cannot be confused by *two* directions. Barred from using the median line of sight, for reasons already fully explained, it must use either the right or left,—must definitely choose between them,—must formulate its judgments on the basis of *one* set of data only;—in a word, must cling tenaciously and exclusively to one direction and totally disregard the other. Of course it cannot use *both,* since to do so would be to use the median. We prefer a reasonable amount of tautology to any possible chance of being misunderstood.

It follows from what has been said that in making tests to determine eyedness and handedness we

must find out which eye does the sighting *when both eyes are open.* This subject will be taken up again in another chapter.

Concerning eyedness itself, there are several points worthy of discussion, even though in the end the discussion prove inconclusive. For instance, it would be most illuminating if we had something convincing in the way of evidence to show whether or not the sighting eye is *structurally,* as well as visually, superior to its fellow. So far as the author has been able to determine, there is an absence of testimony along this line, or at least a decided conflict in such data as are available. Theoretically, whenever the two eyes are structurally equal they should function equally, and standard binocular vision should result. From the rarity of this impartial type of vision, however, and the frequent parity of the eyes from a mechanical standpoint, we are forced to conclude that for sighting purposes the ego seldom fails to make its unilateral choice even when such matters as ocular acuity and refraction are bilaterally equal. If this is true—and it is—it helps to emphasize the fact that unilateral sighting is the fundamental rule, rather than the exception, in normal vision. In other words, when there is uniocular sighting with no apparent difference in the two eyes we find ourselves strengthened in the conviction, arrived at through experiment, that monocular orientation is

indeed a necessary natural development in the evolution of the highest type of vision.

So far we have pursued an inductive course of reasoning, during the progress of which we have had occasion to make certain experiments and examine a number of ascertained facts relating to vision and handedness, until, finally, we have reached the conclusion that handedness is caused by a functional limitation of binocular vision which necessitates the exclusive use of one eye for all sighting or aiming operations, and therefore for many of the most important manual activities. The fact that these visual operations are carried on monocularly leads inevitably to the preferred use of one hand—the hand nearer the sighting eye. Every consideration of speed, accuracy, and economy of muscular effort, and hence the development, safety, and wellbeing of the entire organism demand this intimate correlation of eye and hand on the preferred side.

We are to understand that in the sub-human species the monocular sighting faculty is not confined to one eye exclusively, but fluctuates laterally as needed. Whenever this is the case we find, as in the anthropoid apes, a condition which we are in the habit of describing as ambidexterity, though "non-dextrousness" would perhaps convey with greater nicety the state of absolute manual impartiality resulting from this type of vision. In man, for rea-

sons that will later be detailed at some length, the monocular sighting faculty is usually, though not always, found stabilized in one eye. If this eye happens to be the right, then we are righteyed and righthanded; if the left, we are lefteyed and lefthanded. Occasionally we find persons who possess the older animalian type of vision—the true, standard, or impartial binocularity. These persons are ambidexters, potential if not actual.

Having arrived at this conclusion in regard to handedness generally, the next problem that confronts us is *right*handedness and its almost universal prevalence. Why should this be a righthanded world? In endeavoring to answer this question we shall, in the next chapter, put aside the results achieved by experiment and seek to carry the argument forward by a consideration of some other phases of the subject.

CHAPTER VI

RIGHTHANDEDNESS

Since no authentic traces of handedness have been found among animals, even among the Quadrumana, we are forced to the conclusion that whatever the immediate anatomical or physiological cause may be, handedness itself is probably in some way the outgrowth of man's intellectual development. That it has characterized the race for long ages past is a fact above dispute, testified to by many ancient authorities, as, for example, the reference to the 700 lefthanded Benjamite slingers in the 20th chapter of Judges. We have also the mute testimony of many Assyrian, Greek, and Egyptian sculptures and drawings, proving in more ways than one that for the most part those ancient peoples were righthanded.

To go still farther back, we have it on the authority of Sir Daniel Wilson that cave drawings of the paleolithic age indicate the prevalence of righthandedness at that remote period. The late Professor Frank H. Cushing, of the Smithsonian Institution, some years ago informed the writer that he had been able to deduce from the direction of

the grooves produced by the flaking of stone implements that the great majority of prehistoric artificers were righthanded. Sir John Evans, an authority on the ancient stone implements of Great Britain, came to the same conclusion.

We thus see that in order to discover the earliest traces of handedness we must go far back in the night of time to the primal stages of man's development, perhaps to the period when he first waged warfare with weapons other than his teeth. That this was early in the biologic history of man cannot be doubted, since Darwin and other authorities cite a number of instances to show that the present-day Quadrumana have frequently been known to use sticks and stones as weapons, and sometimes even as tools, clumsily enough perhaps, though at the same time with considerable effectiveness. Another argument for its early development is the fact that it usually appears at about the sixth month in infancy. On the theory that ontogenesis epitomizes phylogenesis this would mean an exceedingly early period in the life history of the race.

Despite the seeming futility of attempting to theorize concerning a mystery whose details are so irrevocably lost in the mists of the far-distant past, we may with a reasonable degree of assurance seek to emphasize several obvious inferences that have almost the character of established fact. In the first

place let us agree, on the strength of the analogy furnished by the Quadrumana, that the immediate ape-like progenitors of man were ambidextrous, and that they used as their sole weapons the rough unfashioned clubs and stones furnished them by nature. As evolution progressed—as cerebral development slowly enlarged the animal's reasoning powers—there would be manifested gradually a *choice* of weapons—a more or less inexpert selection of such sticks and stones as were best adapted to the animal's needs. Following this notable advance in sagacity—perhaps after the further lapse of thousands of generations—there would be evidenced a growing ability of the man-ape to fashion, however crudely, the implements of wood and stone which had now become so all-important in his expanding life and destiny. To break a stone which was too large; to pound off the useless lateral branches of a club; to peel away the bark; to hammer down and remove the sharp protuberances at the small end of his bludgeon in order to secure a better grip;—these would be the first steps in invention and manufacture, involving no small degree of ingenuity and reflection. And at this point in man's development undoubtedly appeared the first tendency to handedness. Ceasing to be a mere animalian machine without preference for right or lefthand usage, the "river drift" man in his first attempts to fabri-

cate his weapons and tools would of necessity rapidly develop unequal manual function,—one hand to be the holding hand, the other to hammer, peel, break, and tear away the superfluous parts of his war-club; one hand to hold the wedge-shaped stone, the other to flake off the chips and give it form and effectiveness, so that it might the better serve him in his battles with the hairy rhinocerous along the banks of the Thames and the Somme.

In other words, he would develop handedness just as soon as his manual activities began to display the first genuine indications of sustained care and precision, because then, and probably not until then, would the expert unilateral sighting faculty be called into action. This deduction is to some extent confirmed by testimony that has been given to show that primitive races are more nearly ambidextrous than highly civilized peoples. Further confirmation is afforded by the statistics gathered by Mr. F. W. Smedley in the Chicago public schools, tending to show a very definite relationship between ambidexterity and dulness. In view of all this we can easily understand why the earliest fathers of the race were in all likelihood ambidextrous. They of course possessed binocular vision, and in consequence sighted laterally. But their sighting ability was not stabilized in one eye; they used for this purpose either eye impartially, *as the Quadrumana do,* and

would have had no use for the fixed unilateral sighting faculty so long as their manual labors were strictly animalian and involved no tasks calling for a high degree of visual attention and concentration.

It is one of the great biologic laws that evolution proceeds in the ratio of differentiation of function, and that heterogeneousness and complexity are synonymous with progress in the ascending organic scale. With this truth in mind we could make out a strong *a priori* case for the inevitableness of man's one-handedness, even though we were grossly ignorant of the facts as they have developed, and even though we had never performed the experiments detailed in the preceding chapters. As soon as he began to fashion club and spear, axe and paddle—just that soon, and measured by the degree of his concentration and his striving for accuracy, there would arise an imperative need of a more stabilized sighting mechanism than is afforded by pure binocular vision—a need that in time would be supplied by the faculty of fixed unilateral sighting, accompanied by handedness. As part of our *a priori* argument we could emphasize the fact that the greater number of manual acts require one hand only, for which reason the attempted expert training of both would be entirely supererogatory; to point out that the necessity for speed, accuracy, and automatic choice of movement would alone tend to that differ-

entiation and specialization of function which is today exemplified in universal one-handedness. Once begun, this preferential use of one hand for expert tasks, however slight and indeterminate it might have been in the beginning, would tend, through repetition, encouragement, and the special advantage it conferred on the individual, to fix and perpetuate itself by virtue of that other biologic law known as natural selection. The one-handed men—the men who possessed the unilateral sighting faculty and had intensively trained one hand, as contrasted with those who still indifferently used two—would become the more expert artisans, the specialists in weapon-making, the more skilled and formidable warriors, with more powerful fighting arms and wrists than their animalian non-dextrous rivals; in short, this concentration and development of manual superiority in one favored hand would alone suffice to distinguish man, the artisan, from his purely brutish kinsmen.

Cuvier considered the human hand so characteristic of the species that he insisted upon a separate order for man under the classification "bimanous." Now, if we designate the anthropoid apes as the "Quadrumana," then little fault could be found with Cuvier's "bimana" to describe, let us say, the ambidextrous and scarcely erect forbears of the Piltdown or Neanderthal men. But in the case of *Homo*

sapiens as he is constituted today, sometimes right-handed and sometimes lefthanded, though never effectively two-handed, if in his case we resort to a classification based on the number of hands, we should not be accused of levity or of entirely disregarding anatomical considerations if we were to call him "monomanous."

In all that has been written on the subject of handedness it is apparently assumed that the race changed from animalian ambidexterity to right-handedness without passing through any marked intermediate stage. A little reflection along the lines we have sketched will show that this is altogether too superficial a generalization and that in order to outline the complete development of manual function we are justified in postulating an intervening period during which lefteyedness and lefthandedness were probably as common as righteyedness and right-handedness. However, to speak of *periods* in evolution may prove somewhat misleading. We will obtain an adequate idea of what has taken place only by remembering that the processes involved were incalculably slow, and that probably at no one time in all the ages has there been any perceptibly radical change. "Natural selection," says Darwin in his *Origin of Species,* "can produce no great or sudden modifications. It can act only by short and slow steps." Let us endeavor then to picture first of all

the shambling ambidextrous pre-glacial man-ape, proud of the sticks and stones which he picks up at random; this type slowly merging after the lapse of ages into a somewhat more intellectual creature possessed of sufficient discriminative ability to examine and choose his weapons; then, evolved by insensible gradations, a still more sagacious being who perceives that it is possible to improve upon the rude weapons furnished him by nature. With this being's first awkward attempts to fashion his own weapons and tools we have the beginnings of fixed monocular sighting and handedness. The time at which this occurred probably coincided pretty closely with man's first serious attempts at intellectual expression through the language of gesture and manual signs. If this is true, there would have ensued that intimate alliance between handedness and speech which still endures, and which dictates that the motor centers for both faculties shall be located in adjacent areas of the dominant cerebral hemisphere.

If what we have said up to this point enables us to account for man's unequal use of the hands, we are nevertheless still faced with the problem as to why the majority of the race should have preferred the right hand to the left. And yet this is a question of relative unimportance compared with the larger one already considered. Why man should

be "monomanus" was the grand problem; how it is that he happens to be "dextromanus" is a matter of secondary interest altogether.

We have already suggested that there was probably a time in man's development, following the early period of general ambidexterity, when lefthandedness was as common as righthandedness,—when as many individuals were sighting along the left visual line as along the right. In order to account for the present numerical preponderance of righthanded persons we have to discover, far back in the past, some predisposing cause or agency which gradually operated to change one-handedness (indiscriminate right and lefthandedness) into a universally predominant dextrality. It is not generally recognized that this cause may have been a very slight and seemingly insignificant one, operating of course over a long period of time. In a previous chapter we referred to the primitive warfare theory suggested by Dr. Pye-Smith, Carlyle, and others as the most likely initial cause of dextral usage; but if this explanation does not satisfy us, we are quite free, for all the direct evidence there is to the contrary, to seek, and with a little ingenuity to build up a case for some other cause, such as sun-worship, finger counting, gesture language, fire making, early architecture, or what not. Whatever furnished the initial impetus, we may be sure that its effect would slowly

be felt in other manual activities. It has always seemed to the author that the cut of skin clothing in primitive times probably left the preferred arm free and exposed, and if so must have vastly *intensified* the dextral usage, once the tendency became manifested. As for the theory of primitive warfare, involving the use of the shield to cover the heart side of the body, while it is assuredly a most plausible one, it is well to remember that the shield was undoubtedly invented ages after the first club and javelin. Meanwhile, as we have seen, the manufacture and use of these weapons alone, long before the shield was thought of, would certainly have induced one-handedness, and might even have developed general righthandedness, since in single combat, the only sort of warfare known in prehistoric times, righthanded warriors could most directly attack their adversaries on the heart side of the body.

But perhaps a more rigorous analysis would place the origin of the mystery still farther back in the drama of man's development. The early progenitors of the race, struggling with embryonic speech in the dawn of the Stone Age and swayed by who knows what barbarous superstition, custom, or necessity, may have initiated and fixed the characteristic for all time. In endeavoring to conjure up from an unspeakably distant past the most probable cause of humanity's righthandedness, some writers have sug-

gested sun-worship as in many ways a likely explanation. For this idea there is a flood of seemingly corroborative evidence which has survived the ages; for instance, what could be more suggestive of ancient sunrise rituals and of the preëminence of righthandedness in earliest times than the fact that in both Hebrew and Sanskrit—and indeed in other languages—the words for "south" and "right" are identical? Likewise we know that the ancient Gaelic *deisul* prescribed movements about a consecrated spot in accordance with the movement of the sun, which is also followed in the Buddhist ritual known as *pradakshina.* In the "Preliminary Discourse" prefixed to Sale's translation of the Koran we learn that the procession of pilgrims around the sacred Kaabah in Mecca is performed in imitation of the motion of the heavenly bodies. It is reported that Tibetans keep sacred objects to the right of them; that the whirling dervish whirls with the sun; that pilgrims circling the holy city of Benares travel with the right hand toward the city; that according to the laws of Manu all sacred objects must be passed with the right hand toward them—in other words in a direction from east to west via the south, following the course of the sun. Classical literature is full of references to similar circumambulatory ceremonies. It seems scarcely necessary to point out that this direction would hold only in the northern

hemisphere. These traces of some ancient parent superstition doubtless led Dr. Brinton, the noted archeologist, to remark that "the notions of good or ill luck connected with one or the other hand are associated with ceremonies relating to reverence paid the heavenly bodies." It may be said in favor of this conception that it carries a certain inherent intellectual appeal, based partly on the very evident antiquity of the customs involved, and partly on what we may term the excessive obviousness of the whole idea.

The author found among some of the native tribes of South Africa a curious tendency to dishonor the left hand by assigning to it all manual acts which are looked upon by these savages as degrading. Thus, to offer food, water, or tobacco to another with the left hand is a monstrous insult. Hertz, in his treatise on religious polarity, states that the Maori tribe of New Zealand consider the left hand profane. An analogous case is cited by Wilson, who says that in the Kingsmill Archipelago of Polynesia the natives call the left hand the "dirty hand." These similar customs may all be survivals of what was once a very general sentiment, although it is doubtful whether we would be justified in assigning the sentiment to any remote period of time. It seems rather more characteristic of Brahminic or Mohammedan, than of pre-glacial, ways of thought.

Whatever furnished the initial impetus to general dextrality, the tendency was probably helped along by the use of the hand in primitive reckoning. The fact that in many parts of the world the word for "five" and "hand" is the same today shows that all antiquity began arithmetic by finger counting, from which practice the word "digit," originally meaning finger, came in time to mean also one of the ten numbers in the decimal method of reckoning, as distinguished from those other systems based on the fingers and toes,—the quinary and vigesimal. That the Roman numerals themselves are but pictures of fingers is self-evident. But a study of primitive reckoning would take us too far afield. We need only say that finger counting, sign language, and gesticulation generally would contribute to the development of righthandedness certain definite intellectual elements that would tend as nothing else to perpetuate and intensify the dextroid impulse.

Summarizing the conclusions to which we are led by the foregoing observations, it seems not unreasonable to suggest:

1st: That earliest man, like the highest apes, possessed pure binocular vision. He sighted laterally, with either eye as needed, and was, therefore, like the simians, ambidextrous.

2d: That the fixed unilateral sighting faculty, accompanied by handedness, developed with the

manufacture and intelligent use of weapons, and that in the beginning it was without any marked general bias for either the right or left side.

3d: That the biological ascendancy of righteyedness and righthandedness subsequently came about through natural selection as a result of one or more now obscure causes, the most likely being the very obvious advantage that would accrue to the warrior who as he faced his opponent carried his spear or club in his right hand. With the invention of the shield this initial dextroid tendency would of course be intensified. There is also a strong probability that sun-worship and its derivitive superstitions had much to do with fixing man's dextrality, which would be further strengthened by finger counting and gesture language.

We are thus brought to the conclusion that eyedness, accompanied by handedness, is a fixed characteristic of the race, pure binocular vision accompanied by ambidexterity representing the ancient parent type, and righteyedness accompanied by righthandedness and lefteyedness accompanied by lefthandedness the two subsequent mutations.[1]

[1] "Both phylogenetic and ontogenetic facts show that the ancestral condition with respect of use of hand was ambidexterity. Anthropological data point in the same direction. Both lefthandedness and righthandedness represent variations from the ambidextral condition." H. E. Jordan, "Hereditary Lefthandedness," *Journal of Genetics,* Vol. 4 (1914), No. 1, p. 77.

CHAPTER VII

TESTS FOR DETECTING NATIVE HANDEDNESS

If the theory of unilateral sighting as the cause of handedness is correct it should be susceptible of proof by some simple test. We ought to be able in some way to determine with certainty the native eyedness and handedness of any person—to show whether righteyedness is accompanied by right-handedness, lefteyedness by lefthandedness, and pure binocular vision by ambidexterity. In primary education and child welfare work it has always been a difficult matter to determine native handedness in doubtful cases. It frequently happens that left-handed children have been trained to use the right hand for so many acts that mere observation of the child's manual habits by no means furnishes a trustworthy basis of judgment. Thus far a reliable and easily applied test has never been perfected. It remained for the present writer, by way of a direct and practical corollary of his theory, to invent a simple device that in a long series of experiments has given excellent results.

The value of a conclusive test lies in the fact that it enables us to deal intelligently and fairly with the child in the matter of manual training. As this is a righthanded world it is important for the wellbeing of every child who displays a tendency to lefthandedness that early in the child's life we determine whether the lefthandedness is congenital or acquired; in other words, whether it is best for the child to conform to nature and go through life handicapped by sinistrality, or whether, in event we discover that the usage is acquired, he shall be made to change. It can be seen that to force a lefthanded child to make dominant use of his right hand when all his sighting is done with the left eye is to force upon him a manual awkwardness that is contrary to the natural order of things. Furthermore, as stated in a previous chapter, this forced reversal of handedness breaks up the intimate grouping of the principal cortical centers and necessitates a transfer of the activities of some of them to the other cerebral hemisphere. It seems reasonable to believe, and observation confirms the idea, that in some degree slowness and indecision are likely to become manifested as a result of disturbing the natural arrangement of these neural centers.

Before describing the workings of the manuscope, the device invented by the author to detect native handedness, it will be well to review briefly the vari-

ous other testing methods that have been devised for the same purpose.

One of the principal methods is the strength of grip test, in which the power of the two hands is measured by an instrument known as the dynamometer. Whipple, in his *Manual of Mental and Physical Tests,* states that results obtained in this way indicate that among children the strength of the left hand is between 91 and 96 per cent. that of the right, and that the superiority of one hand over the other becomes more marked as maturity approaches. Binet and Vaschide found that among children the difference in the power of the two hands, or relative degree of dextrality, varies proportionately with strength, it being less in feeble children.

While the dynamometer enables the experimenter to obtain interesting averages in a long series of tests, the results in individual cases are likely to be untrustworthy, not through any fault of the device itself, but because of varying and necessarily inexact manipulation. It is also true that in some cases strength of grip is not a criterion of handedness at all.

Hall and Hartwell (see bibliography) conducted a number of tests which they describe as follows:

"A ruler about six feet in length was fastened on edge traversely on a table. The person whose move-

ments are to be observed sits with carefully measured squareness before the middle of the table, and places his index fingers on each side of a pin that marks the middle of the edge of the ruler. He intends and then executes a sudden movement along the edge of the ruler to the right with the right, and to the left with the left hand simultaneously, endeavoring to make the excursions of both hands alike."

There are further details, but enough has been quoted to outline the general idea. As a result of a long series of tests the investigators found that "the preferred hand makes the greater excursion."

The crudeness of this test will be apparent to anyone who is at all versed in laboratory methods. Any scheme of this sort will give *approximate* results of interest and value, provided a very large number of tests are made, and provided only the average or mean figures are used. But as a test in individual doubtful cases of handedness it is not sufficiently rigorous and conclusive.

The comparative quickness or rate of movement of the two hands has frequently been computed by the tapping test, and the results used as an index of handedness. This involves the use of a somewhat elaborate electrical device, consisting of a specially designed tapping-board and stylus, a seconds' pendulum, shortcircuiting keys, kymograph (for making graphic records on smoked paper), double time-

marker, stop-watch, dry cells, etc. Sometimes a telegraph sending-key is substituted for the stylus and tapping-board.

Investigations conducted by means of the tapping test show that in righthanded adults the left hand is from 81 to 94 per cent. as efficient as the right, and that in relative tapping ability there is a wider difference between the hands of women than between those of men. Smedley's discovery (referred to in the previous chapter) of a correlation between dullness and ambidexterity was made by means of this test, which in one form or another has been used by many investigators in experiments relating to voluntary motor capacity.

The same objections may be urged against this test as against the others already described. As an approximate index of motor ability in large numbers of cases it gives excellent *average* results; but as a determinator of handedness in individual cases involving abnormalities, or other difficulties and doubts, it is far too fallible.

In order to measure the relative motor control of the hands, arms, and fingers, numerous tests of steadiness have been devised, such as the tremograph, the automatograph, the digitalgraph, Whipple's steadiness tester, and others. These instruments, designed by experimenters in various lines of work, are occasionally used in efforts to determine

native handedness. Careful scrutiny of the data obtained in this way shows that the results do not correlate with the known facts. Aside from this very obvious conclusion, arrived at through experiment, we are likely to decide, *a priori*, that manual or digital steadiness, even if accurately determined, is not a conclusive index of handedness.

The so-called "tracing" test for accuracy and precision of movement belongs in the same category. In this test the subject endeavors to pass an electric stylus between two strips of metal without touching them. Contacts are recorded automatically. Beeley, who made experiments with this test in connection with the "tapping" test already alluded to, claimed that while he could not say that the tests were absolutely reliable, at the same time "their use or application will render the diagnosis of a doubtful case of handedness more accurate and scientific than is possible by any other existing test or method."

Brief mention should be made of the "aiming" tests, in which the subject either makes thrusts or else actually throws at a target. From the standpoint of the writer's theory of unilateral sighting, the underlying idea here is not bad, although the various aiming tests are not devised along lines calculated to achieve the best results. Without describing in detail the methods used, it will be enough

to say that with some drastic modifications these tests could be made much more valuable. As at present conducted, they are successful only in unmistakable cases—cases in which the manual bias is already self-evident.

Efforts have been made to secure an index of handedness by measuring the relative sensitiveness of the two hands to heat and cold. Callousness of the palms, character of the finger-nails, and size of hands have also figured in various tests. Another type of test is based on the relative strength of endurance of the two hands, to measure which the dynamometer and an instrument called the ergograph are both used. The results of all these methods have been inconclusive, particularly in the only type of case in which a test is really needed, i.e., the doubtful case.

Anthropometry has played an important part in the efforts made to provide some reliable method of determining handedness. One of its chief exponents is Professor W. F. Jones, of the University of Southern California, who has devised a system of arm and hand measurements that has aroused widespread interest. In the Jones system measurements are made of the humerus and ulna, plus the distance to the middle knuckle of the little finger; also of the circumference of palm and wrist. A special measuring instrument, known as the brachi-

ometer, is used in obtaining the data. In cases of acquired, rather than native, handedness, measurements are taken of the principal muscles of the arm.

Beeley conducted a series of experiments with the Jones brachiometer and gave his findings in the following language:

"The experimental application of the Jones Brachiometer Test to 123 young children proves its unreliability for extensive use and also the invalidity of the theory upon which it is based, viz., that native handedness can be detected at any age by bone measurements."

The broad general statement that among adults the favored arm and hand are somewhat the larger is undoubtedly correct, but when it comes to actual measurement, especially in the case of young children, the difference between the two arms and hands—if there is a difference—is usually so small as to be practically nonexistent, and therefore non-measurable.

Such in brief are the principal methods hitherto used to detect native handedness. The wide variety of tests and the divergent ideas embodied in them indicate sufficiently well the confusion of thought that prevails on the subject. It is curious to observe that the various experimenters, having failed to discover the *cause* of handedness, content themselves

with measuring *effects;* and it of course follows that since in doubtful cases the effects are not clearly indicated, the tests invariably fail at the very moment that some decisive pronouncement is most urgently called for.

The manuscope determines native handedness by going to the cause. It is thus an indicator not only of handedness, but also of eyedness,—so much so that it might with equal or greater propriety have been called the optoscope. And yet it is by no means a measure of acuity or refraction, nor does it, except in an indirect way, indicate optical disease or malformation. Its sole function is to determine which visual line is used for sighting; and in determining this it helps to determine handedness. The instrument consists of a small darkened box or camera-like chamber, one end of which fits over the eyes and upper part of the face after the manner of a stereoscope, from whence it tapers for 9 inches to a circular aperture 1⅛ inches in diameter at the farther end. Movable shutters on each side of the median line permit of the instantaneous blocking of the right and left lines of sight. There are also three simple diagrams or pictures (marked B, P, and C, Figure 7), mounted upon cardboard; by a simple contrivance B and C may be screened or exposed to view at the will of the operator.

According to the present theory, handedness is

caused by eyedness, the favored hand being the one on the same side of the body as the sighting eye. Now, when doubt exists as to which hand is or should be the favored one, we can determine the essential facts in the case by finding out, with the aid of the manuscope, which visual line is being used as the sighting line.

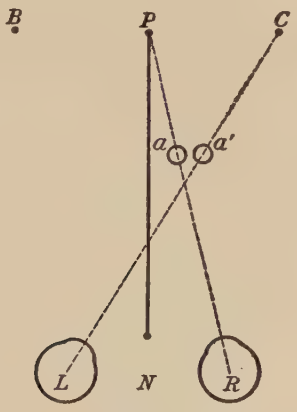

Fig. 7.

The procedure in any given case is simple. Subject should be seated comfortably at a small table, with the light at his back, and cardboard easel, with middle figure (P) alone exposed to view, placed in an upright position about two feet in front of him. Manuscope is then handed to him and a word said as to its use.

Subject is now asked to look through manuscope

at the figure before him. As soon as he indicates that he sees it, operator exposes the other two images, B and C, and asks subject what else he sees.

If in addition to the middle image (P), subject also sees the right-hand image (C), he habitually sights with his right eye and is therefore natively righthanded.

On the contrary, if he now sees the picture or diagram on the left (B), he sights with his left eye and is natively lefthanded.

Frequently there will be found exceptional cases, in which the result of the manuscopic test fails to agree with the ascertained facts. For these cases there are two possible explanations:

First, the original sighting eye may have become visually inferior to the other eye, and in consequence supplanted in all sighting operations by its mate.

Second, the original manual bias may have been changed in greater or less degree as a result of injury to the preferred member, or else through reversed usage prescribed and enforced by parents or teachers.

The facts in any of these exceptional cases can frequently be determined by questioning the subject, using the manuscopic data as a basis for the questions. The possibilities are so few that a simple process of elimination often enables the operator to arrive at the correct diagnosis. Thus, when the as-

certained history of the case indicates a life-long state of handedness which is the reverse of that shown by the manuscope, the operator is justified in suspecting a change of eyedness. The case then becomes one for the oculist. In testing children ocular changes are in this way frequently disclosed for the first time, the trouble not having been noticed previously, even by the subjects themselves.

In making tests with the manuscope the operator should ever remember that eyedness is *cause* and handedness *effect*. We can tamper with and superficially change the effect, but without deliberately disabling the sighting eye we cannot change the cause. In other words, while handedness may to a large extent be changed, eyedness persists and will successfully maintain its original dextral or sinistral character unless for any reason the sighting eye becomes visually incapacitated.

This truth helps us materially in analyzing the results of the manuscopic tests. Thus, when the manuscope shows that the left eye is being used for sighting while the subject is apparently righthanded, the most natural inference is that subject is *natively* sinistral, but that for some reason (injury or training) he has come to prefer the right hand. Or, in the same case, if inquiry reveals beyond a reasonable doubt that subject has always shown a preference for the right hand we can be sure that the right eye

(subject's original sighting eye) has become visually inferior to the left, and has therefore been supplanted by the left in the matter of sighting.

When the manuscope shows that the right eye is being used for sighting, while subject is apparently lefthanded, we may be reasonably sure that if there has been a change of handedness (from right to left) it has not been forced by parents or teachers, but is probably the result of injury to the right arm or hand. If subject's history indicates that he has always been lefthanded, the probability is that there has been ocular trouble resulting in a change of eyedness from the left eye to the right.

It goes without saying that if the result of the manuscopic test agrees with the ascertained facts the diagnosis is to be looked upon as correct.

So much for right- and lefthand cases. If subject has difficulty in seeing middle image (P), or if he shows doubt as to which secondary image appears, and in a series of tests sees first one and then the other, he is to be classed as a mixed type, or as possessing pure binocular vision. Theoretically he should be ambidextrous, although as a matter of fact in these rare cases training and custom usually result in one hand being preferred.

Subject should be instructed to grasp manuscope with both hands. The operator stands immediately behind middle figure of cardboard easel, in which

position he can best manipulate diagrams, and at the same time observe the direction in which manuscope points while in the hands of the subject. In the case of righthanded persons it will point to the right of the central figure; in the case of the left-eyed and lefthanded it will point to the left. Tests should always be repeated in order to eliminate

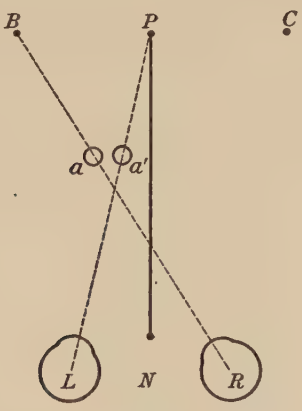

Fig. 8.

doubt. If the result obtained does not agree with the history of the case, tests should be continued until the sighting line is determined beyond any possible question. The movable shutters which permit the blocking of either eye will be found useful in diagnosing difficult cases.

Figure 7 shows diagrammatically the manuscopic results in the case of righteyed and righthanded per-

sons, L and R being the eyes, P the middle picture, NP the median line, *a* and *a'* the heteronymous images of the aperture at small end of manuscope, and B and C the left and right pictures respectively. This is but a logical adaptation of the visual facts epitomized in Figure 6.

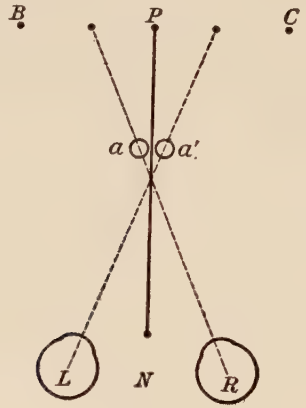

Fig. 9.

In like manner Figure 8 illustrates the workings of the manuscope in the case of lefthanded subjects.

Figure 9 illustrates the difficulty confronting those who possess pure binocular vision. As is shown in the diagram they cannot see the middle image (P) while looking out along the median line; wherefore, if they are to see it at all they too must sight laterally.

Attention is called, parenthetically, to the curiously interesting diagram that may be obtained by combining Figures 7 and 8, as shown in Figure 10.

This diagram has peculiar significance in connection with the study of mirror-writing. For the sake of heightening the effect the lettering has in some respects been changed and corresponding points

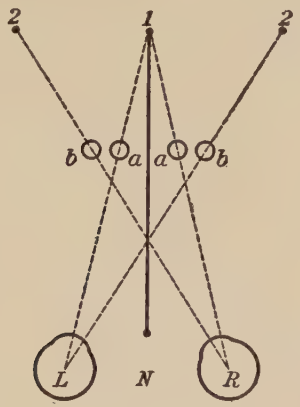

Fig. 10.

indicated by identical letters or numbers. Let 1 represent the point of fixation, 2 the right and left secondary images, and *a* and *b* the heteronymous images of aperture at small end of manuscope; *a* in each case being the image belonging to the sighting eye, and *b* the second or false heteronymous image. Righteyed persons, when looking through manuscope at the point of fixation, see also

the secondary image (2) *on the right,* but not the one on the left. Lefteyed persons see, in addition to the point of fixation, the secondary image (2) *on the left,* but not the one on the right. *The complete reversal or mirroring of the dextral and sinistral visual (and therefore visuo-manual) schemata is here graphically illustrated.* Let it be remembered in this connection that spontaneous mirror-writing occurs *only among lefthanded children, and among righthanded adults who have suffered right hemiplegia and a consequent change of eyedness from right to left,*—in other words, exclusively among persons who use the left visual line for sighting. The diagram helps us understand why it is that if rightward writing is the natural form of writing for the right hand, then mirror-writing is the normal form for sinistrals—a fact that is very generally recognized, though not satisfactorily explained, by many of the leading authorities.[1] That the visual element enters largely into the phenomenon of mirror-writing seems no longer open to question. Fildes and Myers, in their interesting experiments, taught an unlettered mirror-scribbling boy to form

[1] "L'écriture en miroir et de la main gauche est l'écriture normale chez les gauchers dont l'éducation n'a pas faussé la tendance naturelle." Ballet, in *Proceedings of the 13th International Medical Congress,* Paris, 1900, "Section of Neurology," p. 60. For similar expressions of opinion see also the works of Erlenmeyer, Durand, Ireland, Peckham, Vogt, Leichterstern, Clapham, Acker, Mills, List, Wilks, Wray, Kingman, and Buchanan. Their principal argument in this connection is simply that abductive or

letters while blindfolded. With the introduction of the visual factor he drew these letters reversed.[1]

The manuscopic test is easily and quickly applied, and because it makes practically no intellectual or muscular demands on the subject is peculiarly adapted to the examination of children—certainly the most important of all fields in the solving of difficult cases of handedness. To accomplish the maximum good it should be used in the broadest way possible—not only in the more ordinary problems, but experimentally in the case of stutterers, dull and backward pupils, truants, the awkward, the chronically morose, and other abnormal and delinquent types. It will also be found to possess a very real value in therapeutics and surgery, as well as in the skilled trades, in certain sports, in the army and navy, and in other occupations in which the exact determination of eyedness and handedness would make for increased skill and safety. Not the least important use to which it can be put is to enable us to find out *which cerebral hemisphere is the dominant one.*

centrifugal arm and hand movements are more easily performed than adductive or centripetal. That some unknown optical principle might be involved seems never to have been suspected. This principle is indicated for the first time in Figure 10.

[1] See Fildes and Myers, "Lefthandedness and the Reversal of Letters," *British Journal of Psychology,* Vol. 12 (1921), Part 3, p. 273.

CHAPTER VIII

PRELIMINARY MANUSCOPIC TESTS

As indicated in the last chapter there are but three possible results of tests with the manuscope:

First: *Complete agreement between the manuscopic indication and the ascertained facts;* in other words, a correct and unqualified diagnosis.

Second: *A manuscopic indication of righteyedness when the subject is lefthanded.* In these cases it will be found that subject has suffered an injury to the right arm or hand, or loss of acuity in the left eye.

Third: *A manuscopic indication of lefteyedness, whereas subject is righthanded.* In these cases it will be found that subject has changed from left to right-handedness as a result of injury or enforced training, or else has developed trouble in the right eye.

Under the second and third heads the missing data can frequently be obtained from the subject. It happens in an unbelievably large number of instances, however, that subject is totally ignorant of the facts in his own case. There may be eye trouble,

sometimes serious and of long standing, without his being aware of it; or his handedness may have been changed in childhood and the fact completely forgotten. Sometimes lefthanded subjects will declare that they are righthanded, and *vice versa,* these for the most part being persons (of a type well known to psychologists) who misrepresent the facts for the mere sake of appearing odd or different. There are others who consider lefthandedness a disgrace and do what they can to conceal it. Still others, usually sinistrals, set up false claims to ambidexterity. The experimenter must therefore bear in mind that in doubtful cases the information furnished by the subject is frequently of questionable value. Between innocent and wilful misrepresentations of various sorts the investigator's task is not always an easy one. The principal thing to remember in any case is that no matter what the present condition may be, handedness and eyedness were *originally* in strict accord.

One of the virtues of the manuscope is that in addition to the diagnosis it frequently enables us to determine something of the past history of the case. In other words, if complete correlation between the visual and manual elements is lacking, the manuscope not only discloses the fact, but gives a hint as to the cause of disagreement.

This is the place to say something further concerning ambidexterity.

As already explained, true ambidexterity results from a type of binocular vision in which the eyes function impartially. There is, necessarily, lateral sighting, as in all binocular vision; but the faculty is not stabilized in one eye. For example, when the true ambidexter reaches for something with his left hand, his left eye does the sighting; when he uses his right hand, it is the right eye that directs the movement.[1] This is pure binocular vision—the impartial or *fluctuating* as contrasted with the *fixed* type of eyedness. That it is a more primitive form of vision, compared with the kind that characterizes the majority of persons, seems clearly indicated by the fact that it is possessed by the Quadrumana. In it we perceive traces of a form of vision *antecedent to the binocular*—traces of an ancient harmony of function in which eye and limb movements were far more intimately correlated than in man. Lombroso, Lattes, Audenino, and others have declared that ambidexterity occurs most frequently among delinquents; Sherlock has stated that it is "commoner among idiots than among normal persons;" Delaunay came virtually to the same conclusion; Smedley found it most prevalent among the dull and backward; other observers have stated that it is common among the lower human races, notably the Hottentots and

[1] See Fridenberg's criticism of Gould's theory of Ocular Dominance, in *Ophthalmology*, Vol. 1 (1904), p. 196. Fridenberg seems to believe that all binocular vision is of this "fluctuating" type.

Bushmen; Jordan declared it to be the ancient ancestral condition. This testimony serves to emphasize the primitive or animalian nature of ambidexterity, which, indeed, is precisely the undifferentiated non-dextrous usage of the anthropoid apes.

Pure binocular vision is rare, and so, in consequence, is real ambidexterity. But there is a counterfeit type of the latter that is fairly common and is often mistaken for the genuine. We refer to the large number of lefthanded persons who have so thoroughly trained the right hand that they seem to use both with equal facility. Frequently these persons write readily with either hand; sometimes their seeming ambidexterity extends to all the principal manual activities. Often the testimony of the persons themselves is to the effect that they use the hands impartially. A superficial observer might be excused for classifying them as true ambidexters. But let a crisis arise—let there suddenly be demanded some extraordinary manual effort, either of skill, quickness, or strength, and at once, automatically, the ineradicable native bias asserts itself and the left hand is the hand that acts.

With the aid of the manuscope these cases, hitherto considered so puzzling, are easily diagnosed and classified. Cases of genuine ambidexterity are not so easily fathomed, although fortunately for the investigator these latter are rare.

We now present the results of some actual manuscopic tests. In Table 1 are shown the first data obtained with this instrument, the persons examined being twenty miscellaneous subjects, selected at random.

TABLE 1

DETERMINATION OF NATIVE HANDEDNESS IN 20 RANDOM CASES

Subject	Sex	Occupation	Age	Manuscopic diagnosis	Hand most used
1	F	Housekeeper	54	R	R
2	M	Gov't clerk	58	R	R
3	M	Gov't clerk	41	R	R
4	M	Lawyer	42	L	R
5	M	Printer	47	L	L
6	M	Cigar packer	63	R	R
7	M	Printer	18	L	R
8	F	"	21	R	R
9	M	"	25	L	L
10	M	"	23	R	R
11	M	"	26	R	R
12	M	"	20	R	R
13	M	"	35	L	R
14	M	Clergyman	38	R	R
15	M	Salesman	53	R	R
16	M	Storekeeper	51	R	R
17	M	Manufacturer	49	R	R
18	M	Clerk	36	R	R
19	M	Retired farmer	64	R	R
20	M	Clerk	44	R	R

As will be observed in the table, the first discrepancy between the manuscopic diagnosis and the actual manual bias occurred in the case of the fourth subject, who was apparently using the left visual line for sighting, at the same time that he was

righthanded. When the operator conducting the test inquired whether he had *always* shown a preference for the right hand, subject replied very positively in the affirmative. He was then asked about his sight, whereupon he stated that about five years previously his right eye had failed to such an extent that it was now practically useless. He had been under treatment and wore glasses, but did not know the exact nature of his ailment; thought there was "a film over his right eye." This explanation was entirely adequate and satisfactory, and accounted perfectly for the anomalous condition.

Cases like this are more easily solved if we remember that whenever there is disagreement between the visual and manual elements it is to these two factors only that we must devote our attention in order to get a complete history of the case. No other factors enter into the problem. We know that either eyedness or handedness has changed; if not one, then surely the other.[1]

The second discrepancy occurred in the case of subject No. 7. This young man, according to the manuscope, also used his left visual line for sighting, and, like subject No. 4, stated that he had always been righthanded. However, he said that in boxing he was able to use his left hand more effectively than

[1] It is recognized that occasionally they may both change, though this would indeed be a rare coincidence.

his right. In drawing, and especially in working with pastels, he also to a large extent used his left hand. He wrote with his right, and seemed anxious to have it understood that there was no question whatever about his being righthanded. He had never been aware of any eye trouble. When satisfied that nothing further was to be gained by questioning the young man, the investigator looked up and interviewed his mother, who stated that as a child her son had been *strongly lefthanded,* and that much time and patience had been expended in teaching him to use his right hand. This statement fully explained the disagreement between the visual and manual indications, and at the same time showed the folly of relying too strongly on information furnished exclusively by the subject. The case was a good example of the fixedness or permanency of the original sighting line. Subject's father is also lefthanded.

Subject No. 9 was an interesting case. The manuscope disclosed that he habitually used the left visual line for sighting, but when asked if he was lefthanded he replied, "No; righthanded." He was next asked if he had been lefthanded as a child. To this question he replied in the negative. Inquiries were then made as to his sight. This, he said, had always been excellent. After a few more questions the operator dismissed him for the time being and proceeded with

the next test. Half an hour later, as operator was passing through another part of the establishment—a printing shop—he happened to observe subject No. 9 busily engaged in setting type *with his left hand,* holding the "stick" in his right. Subsequent inquiry revealed that he was strongly sinistral, but like many lefthanded persons had educated his right hand to perform many important tasks in the day's work. In this case we have another example of the persistence of the original sighting line, despite a partial change of handedness.

Subject No. 13 was in the same category. He sighted with his left eye, and yet claimed to be right-handed. Said his sight had always been good. He stated that his mother had died when he was eight months old, and that he had been raised by his grandmother. The latter still being alive, though residing at some distance from town, he promised to ask her about his handedness in early childhood and communicate his findings by letter. He subsequently wrote as follows: "I have seen my grandmother in regard to what you would like to know and find I was lefthanded until I was about 4 years old, and as yet when I handle a hay-fork, shovel, pick, etc., I go about it lefthanded—that is, with the right hand at bottom of tool, contrary to the right-handed way." This brief statement does not explain the cause of the change in handedness, though pre-

sumably it came about as a result of corrective training supervised by the grandmother. Again it is to be noted that subject is still ocularly sinistral, notwithstanding the fact that dextro-manual training has gone steadily on for upwards of 30 years. Subject further stated that he had two children, both of whom were lefthanded.

With these four cases straightened out, the detailed analysis of the twenty cases shows a perfect score. The actual testing requires little time;—a minute or two for each subject is ample, provided there are no complications. When the manuscopic indication is at variance with the subject's own statements some further investigation is of course necessary.

It is singularly interesting to note the unerring and rapid manner in which the manuscope does its work. There is a total absence of the slowness, uncertainty, and inconclusiveness of other manual tests; instead, the results are strikingly positive and explicit, furnishing us, even in the most baffling cases (when the disagreement between ocular and manual factors is apparently irreconcilable), with something definite to work on.

If classified in strict accordance with the statements of the subjects themselves, 19 of the above 20 persons would be listed as natively righthanded. Yet the searching examination made possible by the

manuscope reveals a widely different condition of things, showing that 16 are natively righthanded and 4 natively lefthanded. Of the four sinistrals, three have been trained more or less successfully to dextral usage; two of them to such an extent that they probably use the right hand more than the left; the third apparently continues to use his left for the principal manual activities.

We are struck with the high percentage of natively lefthanded persons among these twenty subjects, and even in this limited preliminary test begin to catch a glimpse of a most interesting truth, revealed for the first time by the manuscope, namely, that in all hitherto compiled statistics the alleged great preponderance of dextrals over sinistrals is very much overstated. It becomes apparent that in estimating the number of each we wrongly classify the majority of those natively lefthanded persons whose original bias has been interfered with, and that we include too many of these with the natively righthanded. In other words, we entirely ignore the two great *natural* divisions of natively righthanded and natively lefthanded persons, and adopt a classification based largely on the more or less untrustworthy statements of the persons themselves. It is very evident that in order to have full physiological significance the figures should be based on original native handedness, and not on any subsequent

artificial and partial modification of the original condition.

Baldwin and Hyrtl estimated that 2 persons out of every hundred were lefthanded. Ballard gave the percentage as 2.7. Lombroso and W. F. Jones both thought 4 per cent. more nearly correct. Gould estimated it at 6 per cent. A few others have made it slightly higher. The discrepancy in these figures is presumably due to the fact that hitherto there has been no reliable method of testing native handedness. The manuscope convinces us that all prior estimates of the prevalence of lefthandedness must be revised. We get a hint of this in the twenty cases listed above. If in these cases we base our figures on the statements of the subjects themselves the lefthanded would number but 5 per cent. of the total. Basing the figures on native handedness as revealed by the manuscope we must place the number at 20 per cent.

This matter of the prevalence of lefthandedness will be reverted to later on.

CHAPTER IX

TESTS AT ELIZABETH, NEW JERSEY

In modern school classrooms the desk and lighting arrangements are planned for righthanded pupils. The lefthanded are consequently placed at a disadvantage, since they receive the light over the wrong shoulder. This causes the writing hand to obstruct the light, and frequently results in eye strain. These lefthanded pupils collide with their dextral schoolmates, go through all sorts of contortions to use the armchairs, and occasionally, when the teacher is not particularly resourceful, are neglected in the matter of instruction. Lefthandedness is therefore one of the serious problems confronting the educators and teachers in our primary schools. Endless discussion has failed to solve it. The usual makeshift solution, in the absence of a proper understanding of the nature of handedness, is to treat everyone alike—to make all conform to the dextral practice of the majority. One can scarcely blame those in authority for following this easy way out of the difficulty. It is even possible that, all things considered, they are right. Let it be remembered,

in extenuation of their course, that our public schools are still in the early experimental stages of development, and that this striving for the greatest good to the greatest number—almost the sole justification for mass instruction, and for mass treatment of handedness,—is, in the present circumstances, probably the only feasible policy.

The general verdict among teachers in the primary grades of our public schools is that the majority of lefthanded pupils may safely be taught to write with the right hand without incurring any subsequent harmful effects. Some teachers, however, differentiate between degrees of lefthandedness and recognize a class of "strongly" lefthanded, or "real" lefthanded pupils whom it is difficult to change. As there is but one kind of native lefthandedness—the kind that depends on the habitual use of the left visual line for sighting—any difference is simply one of *intensity* or *persistence,* qualities that in many cases probably indicate that the characteristic is not only inherited, but is of duplex origin, implying extraordinary strength of the visuo-manual coördination, along with what we may call an inherited reluctance of the left cerebral hemisphere to assume and develop the sinistral faculties which are sought to be transferred.

We might as well recognize the fact that when we make righthanded writers out of lefthanded school-

children we do not necessarily cause them to use the right hand for other manual activities. As a usual thing writing is the only manual act of left-handed pupils that is thoroughly supervised. Other sinistral tendencies for the most part go unchecked. It follows that in these cases writing is often the sole dextral accomplishment. Sometimes the writing act is accompanied by various other dextral usages, and not infrequently we come across cases in which the educated right hand seems to have superseded the left in nearly all the principal manual activities. The extent of the change depends of course on the thoroughness of the training in school and home, as well as upon the adaptability of the pupil. It is small wonder that there are so many mixed cases of handedness, so many different brands of alleged ambidexterity; and we can well understand that classifying the variegated types is almost a hopeless task when any of the usual tests are used. The manuscope helps us to classify them with scientific exactness.

The present writer is convinced that change of handedness seldom results in stammering or other speech defects, provided the change is made at an early age. This view has been amply confirmed by extensive observation and experiment. For instance, in Elizabeth, N. J., as in many other places, the school authorities have for some years made a prac-

tice of training all lefthanded pupils to write with the right hand. The author's attention was called to the situation in Elizabeth by a brief item in the daily press, reading as follows:

LEFTHANDEDNESS IS CURED AMONG PUPILS

ELIZABETH, N. J., Nov. 20 (1922).—An intensive campaign to cure lefthandedness among pupils in local schools here has resulted in a reduction from 250 to 66 since 1919.

In the enrollment of nearly 13,000 this is slightly more than one-half of 1 per cent.

After some correspondence with the school authorities at Elizabeth, the author was permitted to study the results of their policy and at the same time make certain manuscopic tests among the pupils. It was his desire to ascertain whether any cases of stammering could be traced to enforced changes of handedness; also to make a large number of manuscopic tests and so gain for the first time some definite idea as to the real prevalence of native lefteyedness and lefthandedness.

Investigation showed that in the four years that the policy had been in effect in Elizabeth not a single case of defective speech could be traced to reversal of manual habit. In one or two cases of stammering the change from left- to righthandedness had at first been suspected of causing the trouble; but careful inquiry revealed that the defect unquestionably existed prior to the pupil's entrance into school. As the total public school enrollment

at the time this investigation was made was about 15,000, and as practically all lefthanded pupils were made to write with the right hand, this result in a period of four years was impressive.

The whole Elizabeth experiment demonstrates the fact that when reversal of handedness takes place early in life it is seldom accompanied by any noticeably bad effects. At this stage of development body and brain are in a plastic state, and adjustments which later in life would be out of the question are made with ease. Thus, the lefthanded pupil, five or six years old, learns to write with his right hand with scarcely more difficulty than would be incurred in training the left. In order to facilitate the change, Mr. Gudmundson, supervisor of writing in the Elizabeth schools, has devised a scheme whereby the lefthanded child is always required to do his first writing *on the blackboard*. The idea here is that the element of novelty involved in blackboard and chalk makes it easier for the teacher to inaugurate the second novelty—the use of the right hand. Any previous lefthanded scribbling with pencil is now lost sight of by the pupil and a fresh start is made with the new implements and newly discovered hand. The idea seems to work splendidly.

From his study of speech defects the present writer is led to believe that whenever stuttering occurs as a result of changing the native handedness of

young children it lasts while the change is being made, and no longer. If the corrective training is continued until the change becomes a *fait accompli* the stuttering will, in a normal child, disappear. If it does not disappear we must believe that centrally the change has not been made, probably because the brain cells of the motor speech area in the left hemisphere are functionally deficient, and therefore unequal to the task imposed upon them by the radical shift of cerebral activity from right hemisphere to left. When the stuttering persists, all efforts to effect a change of handedness should of course be abandoned. Claiborne's investigation in this important phase of the subject seems to bear out these conclusions.[1]

The series of manuscopic tests in Elizabeth began on October 30, 1923, and continued during four days. A total of 877 pupils were examined, nearly all of them attendants at Public School No. 9, on Jacques Street. Mr. Chapman, Superintendent of Schools, was fortunately most keenly interested, and at his direction every assistance was rendered the investigator. A special room was given over to the tests;

[1] See especially his "Stuttering Relieved by Reversal of Manual Dexterity," in the *New York Medical Journal,* Vol. 105, No. 13, pp. 577 and 619. This pathological phase of the relationship between handedness and speech is dealt with also by Fildes and Myers, Jordan, Scripture, Whipple, Lueddekens, Tompkins, Ballard, Blanton, Gould, Nice, Quinan, Stier, W. F. Jones, Major, Mott, and numerous others.

the various classes were marched to the door of this room, and the pupils, one at a time, were rapidly admitted and tested with the manuscope. It was found that in this way about fifty tests per hour could be made.

In Table 2 is presented a general analysis of the results of these 877 tests, showing that 608 pupils, or 69.33 per cent. of the total number, used the right visual line for sighting; 257, or 29.30 per cent., used the left visual line; and 12, or 1.37 per cent., used the right and left visual lines impartially.

The most significant thing about these figures is the relatively large number of lefteyed children—nearly one-third of the total. According to the present theory all these are, or were, natively lefthanded, with the possible exception of a comparatively few righthanded persons who on account of ocular trouble have suffered a change of eyedness and now use the left visual line for sighting.

It is recognized that this view is not likely to be accepted without some further substantiation of the facts; the figures are too large—the assumptions too radical. The usual estimates of the number of lefthanded persons range from a mere 2 to 6 per cent., the average being about 5 per cent. Here we have six times that number. Obviously some further data are required before the figures can be expected to

carry conviction. These we shall attempt to furnish in what follows.

In Table 3 is shown a detailed analysis of the *righteyed* pupils, with respect to handedness. It might be well to state that the numerical equality of

TABLE 2

MANUSCOPIC TESTS OF 877 PUBLIC SCHOOL CHILDREN, ELIZABETH, NEW JERSEY

Teacher	Grade	Number tested	Average age (years)	Right-eyed	Left-eyed	Im-par-tial
Beatty	1b	46	6.33	29	15	2
Emmel	"	44	6.16	31	11	2
Marone	1a	45	6.97	36	8	1
Kirkman	2a	42	7.88	28	13	1
Rothhouse	"	43	7.33	31	11	1
Frazer	3b	31	8.42	16	15	..
Quincy	"	31	8.56	20	9	2
Rogers	"	31	8.68	26	5	..
Giglio	"	27	7.91	24	3	..
Connelley	3a	44	9.16	29	15	..
Higgins	"	41	8.61	27	14	..
Mulford	4b	35	9.77	19	16	..
Cullen	4a	42	10.98	30	11	1
Trowbridge	5b	49	10.45	32	17	..
Kent	5a	37	11.32	20	16	1
Reibel	6b	30	11.73	21	8	1
Skidmore	6a	43	12.16	32	11	..
Gray	7b	40	12.27	29	11	..
Garrison	7a	25	12.88	17	8	..
Story	"	18	12.44	13	5	..
Featherston	8b	36	12.81	27	9	..
Gartz	"	34	13.67	22	12	..
Smith	"	29	13.17	21	8	..
Day	8a	34	13.85	28	6	..
		877	9.90	608	257	12
		100%		69.33%	29.30%	1.37%

the sexes, as shown in this tabulation, was entirely accidental and in no wise intended.

TABLE 3

HANDEDNESS OF 608 RIGHTEYED PUPILS OF THE PUBLIC SCHOOLS OF ELIZABETH, NEW JERSEY

Teacher	Grade	Number righteyed pupils			Right-handed	Left-handed	Remarks
		Male	Female	Total			
Beatty	1b	13	16	29	29		
Emmel	"	17	14	31	31		
Marone	1a	18	18	36	36		
Kirkman	2a	17	11	28	28		
Rothhouse	"	17	14	31	31		
Frazer	3b	10	6	16	16		
Quincy	"	8	12	20	19	1	Boy, 10 years old, claimed to be lefthanded; had no eye trouble that he knew of.
Rogers	"	19	7	26	26		
Giglio	"	20	4	24	24		
Connelley	3a	17	12	29	29		
Higgins	"	13	14	27	27		
Mulford	4b	12	7	19	19		
Cullen	4a	10	20	30	30		
Trowbridge	5b	14	18	32	32		
Kent	5a	8	12	20	20		
Reibel	6b	13	8	21	21		
Skidmore	6a	12	20	32	31	1	Girl, 14, claimed to be lefthanded in everything but writing; said that her left eye was weak.
Gray	7b	15	14	29	29		
Garrison	7a	8	9	17	17		
Story	"	7	6	13	13		
Featherston	8b	8	19	27	27		
Gartz	"	12	10	22	20	2	Girl, 15, claimed to be lefthanded; no eye trouble that she knew of. Boy, 14, claimed to be left-handed; said that his sight was faulty—his right eye the better of the two.
Smith	"	5	16	21	21		
Day	8a	11	17	28	28		
Total		304	304	608	604	4	

These figures tell their own story and require little comment or explanation. Of the four left-handed cases, two explain themselves, the subjects

being native sinistrals whose original sighting eye (the left), because of the development of some ocular fault, has been superseded by the right. Since the subjects were well aware of their eye trouble a correct diagnosis became an easy matter. The other two cases differ from these in one respect only: the subjects knew nothing of the trouble, whatever it was, that caused the left eye to be supplanted by the right in the matter of sighting. But the fact that they were sinistrals who habitually preferred the right visual line was *prima facie* evidence, disclosed by the manuscope, that the eye trouble existed. The only other explanation possible was change of handedness due to injury to the right arm.

Analyzed in this way, the four exceptions fall into one category. Let us invent a convenient term and call them *righteyed sinistrals.* The fact that there should be only four of these cases among 608 right-eyed children is a point that deserves special emphasis. It is evident that in childhood the sighting line seldom changes.

But what chiefly impresses us in these figures is the remarkable agreement of handedness with eyedness. The complete correlation of these two apparently separate and distinct functions throughout 600 consecutive cases could not well be the result of chance. The odds are infinitely against it. There is unmistakably some definite physiological law at

work. Can it any longer be doubted that of the two functions one is cause and the other effect?—in other words, that unilateral sighting, the necessary adjunct of binocular vision, is at once the cause and concomitant of handedness?

To grasp the full significance of these figures we should look upon the four lefthanded cases not as exceptions to the general rule, but as strong confirmation of it. To put it differently, the theory explains not only the 604 cases in which there is perfect coordination between the visual and manual elements, but also the four special cases in which the visuomanual harmony has been violated.

Changes of eyedness are of course to be looked for in increasing numbers as the pupils advance in age. In the above tabulation the four cases in which the eye function has changed are too few to prove of statistical value, though even here the tendency to progressive increase with age is indicated.

The theory of unilateral sighting as the cause of handedness has certain inherent elements of strength quite apart from anything in the nature of direct proof. It is simple, obvious, concrete, reasonable. To state it fairly is almost to prove it. And yet the experimental verification afforded by these figures is none the less gratifying. To the author the agreement of the figures was somewhat startling. This

remarkable agreement must be borne in mind when we come to interpret the remaining data furnished by the tests. At this point let us reinforce our position by once more stating the summary of results thus far obtained.

Out of a total of 877 subjects we find that 608 use the right visual line for sighting. With four exceptions that properly belong in a separate category, all these righteyed persons are righthanded.

For reasons which will become apparent as we proceed with the further analysis of the tests, this unbroken relationship between eye and hand is not shown in the case of the lefteyed pupils, as will be seen in Table 4.

Table 3 impressed us with the remarkable agreement or parallelism of the figures therein contained. In Table 4, on the contrary, we are struck with the great number of disagreements. Out of a total of 257 lefteyed pupils, but 32 confess to being lefthanded. Those who state that they are righthanded are seven times as many. How are we to reconcile these discrepancies? How explain them on the theory of unilateral sighting?

In the first place it must be remembered that these tests are designed to determine the *original,* rather than the *existing* condition. Eyedness, we have discovered, seldom changes, and for this reason furnishes a clue to the original lateral bias. We follow

TABLE 4

HANDEDNESS OF 257 LEFTEYED PUPILS IN THE PUBLIC SCHOOLS OF ELIZABETH, N. J.

Teacher	Grade	Number lefteyed pupils			Left-handed	Right-handed	Remarks
		Male	Female	Total			
Beatty	1b	7	8	15	2	13	3 of the righthanded say that they used to be lefthanded.
Emmel	"	4	7	11	2	9	2 now righthanded used to be lefthanded; another uses left for sewing.
Marone	1a	5	3	8	1	7	2 now righthanded used to be lefthanded.
Kirkman	2a	9	4	13	3	10	2 now righthanded used to be lefthanded.
Rothhouse	"	5	6	11	..	11	1 now righthanded used to be lefthanded.
Frazer	3b	8	7	15	2	13	3 now righthanded used to be lefthanded.
Quincy	"	4	5	9	..	9	1 throws ball lefthanded.
Rogers	"	3	2	5	..	5	2 write with either hand.
Giglio	"	3	..	3	1	2	
Connelley	3a	10	5	15	1	14	4 righthanded write with either hand; another has bad right eye.
Higgins	"	5	9	14	1	13	1 righthanded used to be lefthanded; 2 others write with either hand.
Mulford	4b	7	9	16	4	12	2 righthanded have eye trouble; another writes with either hand; another throws ball with left.
Cullen	4a	6	5	11	2	9	2 righthanded used to be lefthanded.
Carried forward		76	70	146	19	127	

TABLE 4—(*Continued*)

Teacher	Grade	Number lefteyed pupils			Left-handed	Right-handed	Remarks
		Male	Female	Total			
Brought forward		76	70	146	19	127	
Trowbridge	5b	9	8	17	2	15	1 righthanded throws with left; another writes with either hand; another uses left for sewing; another says he used to be lefthanded.
Kent	5a	9	7	16	2	14	2 righthanded write with either hand; another has a bad right eye.
Reibel	6b	8	..	8	..	8	
Skidmore	6a	4	7	11	3	8	1 righthanded used to be lefthanded.
Gray	7b	6	5	11	2	9	1 righthanded has a bad right eye.
Garrison	7a	4	4	8	1	7	1 righthanded writes with either hand.
Story	"	2	3	5	..	5	
Featherston	8b	4	5	9	..	9	1 righthanded throws with left; another used to be lefthanded.
Gartz	"	7	5	12	2	10	1 righthanded used to be lefthanded; another has eye trouble.
Smith	"	3	5	8	1	7	
Day	8a	..	6	6	..	6	
Total	..	132	125	257	32	225	

Of the 32 lefthanded, 22 were male, 10 female.
Of the 225 righthanded, 107 were male, 118 female.

this clue—we determine which visual line is habitually used for sighting; and on the basis of this determination make our finding of *native* handedness.

There is but one thing that can invalidate our diagnosis, and that is eye trouble sufficiently serious to cause a change in the sighting line.

Applying these principles to our study of the figures in Table 4, we must realize that despite all the discrepancies, despite the relatively large number of pupils comprised in the tabulation, despite any previously entertained ideas as to the prevalence of lefthandedness, virtually all these lefteyed subjects, no matter what their present manual habit may be, were originally (and in some important respects still are) sinistral. The only exceptions are a comparatively few natively righthanded subjects who have experienced a change in the sighting line, due to ocular trouble.

Approaching the problem of these discrepancies in a somewhat different way, let us ask ourselves where we should expect to find changes of handedness if not among the lefthanded. Normal *right*-handed children are not changed. Of course injury to the dextral member may occasionally force a change from right to left, but otherwise all changes are from left to right. We are not surprised, then, that there should *be* discrepancies, but simply that there should be so many. The *number* is what astounds us; this only because we happen to possess certain preconceived notions as to how many lefthanded persons there ought to be. These precon-

ceived ideas we obtain from estimates based on actual dextral and sinistral usage, rather than on congenital tendencies. That the original tendency is frequently frustrated we already know. How often it is frustrated we learn for the first time from Table 4. With these truths in mind the figures appear somewhat less startling.

Again: we are warranted in giving credence to these figures because of the strong corroboration of the theory furnished by Table 3, in which the exact relationship between eye and hand is shown beyond question. Having found that of the hundreds of children examined, virtually all the righteyed are at the same time righthanded, we are justified in believing that the natively lefteyed, irrespective of their present manual preference, were all originally lefthanded.

The credibility of the figures is further emphasized by the fact that of the 36 confessed sinistrals in both tables, 32 are lefteyed. The remaining four, having experienced a change of eyedness, belong in a slightly different classification. We must of course assume for them an original condition similar to that of the 32 whose eyedness has not changed.

These four "righteyed sinistrals" are a possible index of the number of natively righthanded subjects whose eyedness has changed and whom we may

now expect to find among the lefteyed. If changes of eyedness among the natively righteyed occur in the same proportion as among the natively lefteyed, we should find among the latter in Table 4 nine or ten originally righteyed subjects. No verification of this deduction was attempted, however, and no claim is made that the same proportion would hold in any other series of tests. Changes of eyedness probably vary with conditions, especially with social conditions. General eye examinations were not a part of these tests, but in 6 cases (Table 4) in which eye trouble was evident, 3 pupils stated that the right eye was bad, while the other 3 did not know which eye was especially affected.

Indirect corroboration of the figures in Table 4 is to be found in various studies which have been made of the inheritance of handedness. The stumbling block in all these investigations has been the relatively small number of sinistrals. How left-handedness has been preserved throughout the ages if it occurs in a mere 2 to 6 per cent. of the population has been hard to explain on any of the known, or even suspected, principles of inheritance. The Mendelian laws, which in numerous ways (congenital cataract, to cite but one example) have been found to apply in human heredity, are believed by several authorities to govern the transmission of handedness. Future manuscopic studies should set-

tle the question conclusively. Jordan, whose work in this connection is particularly striking, was apparently the first to demonstrate that the inheritance of lefthandedness follows Mendelian principles. Hurst and Ramaley both subsequently confirmed this finding, Ramaley at the same time making the interesting statement that *lefthandedness exists in about one-sixth of the population.*[1]

So far as the author is aware, this large estimate is the first marked departure from the small figure (2 to 6 per cent.) usually given by writers on the subject. It is a step in the right direction, since it presumably takes cognizance of a large natively sinistral element that has previously escaped observation—the numerous class of natively lefteyed and lefthanded persons whose manual habit is changed in infancy or early childhood and who are subsequently counted among the righthanded. This is the class with which we are chiefly concerned in Table 4.

Ramaley's estimate thus serves to add a measure of plausibility to the figures now under consideration, although we cannot but realize that there is a vast difference between 16⅔ per cent. and 29.30 per cent. However, in 1914, Jordan, pursuing the subject still further, came to the conclusion that righthandedness is "now present approximately in

[1] *American Naturalist,* Vol. 47 (1913), p. 738.

the ratio of 4 to 1." [1] In other words, we have here an estimate of 20 per cent. as the present relative number of sinistrals. This is still another step in the right direction.

It was with great satisfaction that the author, at this point in his labors, accidentally ran across an estimate by Bardeleben, as reported in the *Journal of Heredity,* giving the number of lefthanded children as 6.8 per cent., *and the number of lefthanded children who have been changed to righthandedness as 26 per cent.*[2]

The 225 "lefteyed dextrals" in Table 4, nearly all of whom, according to the theory of unilateral sighting, have been changed from left to right, *are 25.66 per cent. of the total,* a very striking agreement with Bardeleben's finding.

The 36 confessed lefthanded pupils (4 in Table 3, 32 in Table 4) are but 4.1 per cent. of the total number tested, falling short of Bardeleben's figure by 2.7 per cent., but agreeing sufficiently well with numerous other estimates that might be cited.

This close agreement with Bardeleben does not constitute proof, but it does give the figures in Table 4 an air of respectability which they almost totally lacked when we first looked at them.

The few questions rapidly put to each pupil as he

[1] *Journal of Genetics,* Vol. 4 (1914), No. 1, p. 78.
[2] *Journal of Heredity,* Vol. 5 (1914), No. 7, p. 312.

was being tested developed strong evidence that many of the 225 were natively lefthanded. Thus, 20 stated outright that they used to be lefthanded; 13 demonstrated that they could write well with the left hand, one of these being a mirror writer; 4 stated that they threw with the left when playing ball; and 2 said that they held the needle in the left hand when sewing. These 39 significant statements give a hint as to what a more detailed investigation of each case might have developed had time and circumstances permitted.

Reverting to the question of the hereditary transmission of handedness, let it be recalled that according to the present theory there was a time in man's development when lefthandedness was as prevalent as righthandedness (see pages 62 and 64). If this be granted, and if we further accept the general belief that righthandedness is the dominant and lefthandedness the recessive character, then according to Mendelian principles our 29.30 per cent. conforms very closely to expectation.

In order to confirm this view the author submitted the question to Dr. Jordan, of the School of Histology and Embryology, University of Virginia. Dr. Jordan, who has written so ably on the subject of hereditary lefthandedness, expressed his opinion in the following language: "Assuming that originally lefthandedness and righthandedness occurred in

the proportion of 1 to 1, and further that lefthandedness acts in inheritance as a Mendelian recessive (for which there is considerable evidence), then it would follow on the basis of the Mendelian principles that (barring selective mating) lefthandedness and righthandedness would eventually occur in the proportion of approximately 1 to 3."

All will agree that lefthandedness is not selected against in mating, so that the 1 to 3 ratio holds true. It was with this idea in mind that we intimated that the laws of inheritance indirectly corroborate the figures in Table 4.

It is realized that while these Elizabeth tests will be looked upon by many who are accustomed to weigh scientific evidence as fully substantiating the theory of unilateral sighting, at the same time others will want something more conclusive regarding the "lefteyed dextrals." Future tests will doubtless be conducted under conditions that permit of a complete checking of the data relating to this class. We risk nothing in predicting that whenever a full history of the case is available the manuscopic indication will be fully confirmed. Occasional difficulties may of course be looked for. For instance, the original bias may in some cases be so slight that in infancy a change in the native manual habit might take place without the *conscious* exertion of any special corrective effort on the part of parents or

others responsible for the child's upbringing, and therefore without any knowledge on their part that corrective measures had ever been applied. If these cases exist, and we have strong *a priori* reasons for believing that they do, they will be found to occur infrequently.

An important line of future investigation will be the experimental determination of the exact degree and character of eye trouble necessary to cause a change in the sighting line.

CHAPTER X

CONCLUDING REMARKS

Sir Daniel Wilson, speculating on the origin of righthandedness in his very erudite book on the subject, makes use of the following language: "A very slight consideration of the evidence already adduced in proof of the same prevalent usage from the earliest times precludes the idea of its origin in any mere prescribed custom, enforced and developed by education into a nearly universal habit. This becomes the more manifest when it is traced back to primeval races, found incorporated in ancient and modern savage and civilized languages, and uncontroverted by any evidence calculated to discredit the indications that it was a characteristic of paleolithic and neolithic man. The inevitable conclusion forced on the inquirer is that the bias in which this predominant law of dexterity originates must be traceable to some specialty of organic structure." [1]

The same conviction has been expressed in one form or another by a majority of the writers on handedness. We now in all modesty submit that the

[1] *The Right Hand: Left-Handedness,* Macmillan, 1891, p. 150.

theory of unilateral sighting furnishes the specific physiological reason so long and earnestly sought for as the real solution of the mystery. And while we believe that serious objection cannot be taken to this statement, the point may be raised that there is less of physiology than of psychology in the development of the theory. It may be urged that we have the strongest grounds for believing that in binocular vision the images of each eye reach consciousness entirely separate and distinct; and that in unilateral sighting, as in strabismus, one image is suppressed or disregarded,—a circumstance that would seem to place the various phenomena among those belonging to the psyche, rather than in the less intangible realm of practical physiology.

Withholding judgment in these matters and resisting any temptation to seek the *ultimate* principles involved (assuredly a far and in the end a vain quest) we rest our case on several concrete, demonstrable truths, among them the fact that it is impossible to sight binocularly,—that for some of the most important visual operations we are consequently in effect one-eyed,—that with both eyes open we use, in sighting, but one; and that because of this frequent and necessary one-eyedness we are naturally, automatically, and inevitably one-handed. Now, irrespective of psychic considerations there is

certainly something strongly physiological in a law as tangible and as fixed as this.

The fact that eyedness—the exclusive use of either the right or left visual line for sighting—persists most tenaciously under adverse conditions has been fully demonstrated by the manuscope in tests of school children and others whose native handedness has been reversed. Indeed, careful investigation of this phase of the subject justifies the statement that except in cases of visual failure the sighting line does not change. If for any reason the sighting eye becomes greatly incapacitated, the sighting faculty may of course pass to the other eye; but this is apparently the only cause of changes of eyedness.

This fixedness of the unilateral sighting line despite changes of manual habit is significant in several respects. In the first place it furnishes added proof of the dominance of the corresponding cerebral hemisphere in at least some of the visual operations, and indicates a reluctance of the organism to transfer the monocular sighting faculty to the visual areas of the other hemisphere, notwithstanding that each macular region is connected with *both* hemispheres.

In the second place this tendency to fixedness on the part of the sighting line impresses us with the importance of eyedness as a permanently acquired faculty of the human organism, and enables us the more readily to understand the logic of the devel-

opment of handedness, which we thus perceive to be an inevitable and most necessary natural provision, and not, as is so often thought, a merely accidental, inconsequential, or evanescent characteristic without reason or purpose.

Moreover this fixedness of the sighting line settles most convincingly a point that otherwise might be somewhat difficult to clear up. We refer to the question as to which (of handedness and eyedness) is cause, and which effect. Experiments with the manuscope supply the answer and show us that while changes of handedness are always deliberately brought about, changes of eyedness are involuntary. In the one case the change is the result of design, in the other of nature. To put it differently, we can tamper with and to some extent control and change handedness, but we cannot permanently change the inherent cause of handedness.[1]

The predominant function of eye as compared with hand is also suggested by the earlier development of the visual apparatus in the human fœtus. The primitive optic vesicles are present *as early as the 12th day,* and thereafter development is rapid.

[1] An interesting line of investigation here suggests itself: In infancy would the loss or serious disabling of the sighting eye and the consequent enforced transfer of the sighting faculty be followed by a transfer of handedness? With adults of fixed manual habit and perfected cerebral mechanism this would scarcely be possible; with children of very tender age it might be, provided the speech and other closely coördinated centers had not become too firmly established.

As a significant point in the study of bilateral evolution it is well to note here that the rudimentary eye is entirely lateral, as in fishes and batrachians, and remains so until about the 40th day, when it begins to turn obliquely forward. What is true of the embryo is true of the phylum; the eyes have come forward, and probably to some extent the arms also.

From what has been said it now becomes evident that in reversing handedness the question is not so much whether certain manual acts can still be performed under the new condition, but whether the sighting line and the entire lateral preference can be changed. For instance, it is not a difficult matter to make a righthanded out of a lefthanded writer, especially in childhood; but in the broadest sense this is not changing the writer's native handedness, which is governed solely by his eyedness. Dr. Edwin B. Twitmyer, of the Psychological Laboratory of the University of Pennsylvania, has summed up the matter very tersely: "In my opinion," he says, "it is impossible to change a congenitally left-handed child into a right-handed child. There is no evidence on record that this has ever been accomplished. It is possible to train left-handed children to many finely co-ordinated movements, such as writing with the right hand. From my point of view this is desirable and renders the

child less awkward in an environment constructed for right-handed people. Under ordinary circumstances no damage is done the child by such training." [1]

It is safe to assume that supererogation finds no place in the economy of nature, and that everything that smacks of it belongs in the realm of the abnormal and pathological. With this truth in mind we are justified in looking with suspicion upon cases of handedness in which the visual and manual elements are not in the strictest accord, and in classifying such cases as deviations from the normal. With eyedness firmly intrenched on one side of the organism and handedness struggling along on the other, there result an indirectness of action and a waste of effort that seriously interfere with the lateral harmony of function so necessary to bodily wellbeing and efficiency. The organism may be said to dissipate a valuable portion of its energies in antagonizing *itself,* instead of conserving and concentrating its powers for the all-important struggle with its environment.

Such evidence as we possess leads to the conclusion that unilateral sighting is an ancient visual accomplishment necessitated by certain inevitable limitations of the binocular mechanism. We have

[1] *Palmer's Teachers' Guide,* The A. N. Palmer Co., New York, 1923, p. 54.

every reason to believe that binocularity is never wholly without it. In its cruder form it is probably older than binocular vision, very likely a survival from earlier biologic types in which the eyes had independent motion and function. This view seems to leave out of account several extremely pertinent facts that might argue a different conclusion, such as the apparent absence of eyedness in the Quadrumana, and the prevalence of ambidexterity among primitive races and among the feeble-minded,[1] notwithstanding that the Quadrumana and these lower types of the human species all possess binocular vision. We tell ourselves that if the unilateral sighting faculty is a necessary accompaniment of binocular vision we should find handedness developed in all these cases. Its absence fully warrants us in postulating *two kinds of eyedness:* First, an older and more elementary form in which the sighting faculty fluctuates from eye to eye as need arises, and which causes true ambidexterity in the simian and in a comparatively few of the human species; and second, the more highly specialized *fixed* type of eyedness which characterizes the generality of the

[1] Lombroso, Lattes, and Weber all observe that ambidexterity characterizes the anthropoid apes, and in the human race is most prevalent among infants and idiots. Lombroso states that "ambidexterity more than left-handedness represents an atavistic character." Jordan reaches practically the same conclusion; see p. 69 (footnote). Interesting data concerning the prevalence of ambidexterity among idiots are given in Sir James Crichton-Browne's *Dexterity and the Bend Sinister.*

human race today and which is the direct cause of handedness.

This view is confirmed by the ontogenetic fact that infants are very generally ambidextrous, handedness not appearing until the sixth or seventh month, or later.[1] On the theory that ontogenesis is an index of phylogenesis, this indicates, first, that the race was originally ambidextrous, and second, that a fixed degree of eyedness and handedness appeared at a very early period in the life history of the species.

Reviewing the whole case in the most general way we see that with the exception of some of the insects the animal world generally has two eyes, although, as already pointed out, in the lower forms the neural decussation is complete and each eye moves independently. In the higher forms we find binocular vision, accompanied by some sort of lateral sighting. In the Quadrumana, and occasionally in the human species, this sighting faculty is not fixed, but fluctuates laterally, according to whether the visual stimuli are dextral or sinistral. The vastly greater number of the human race, however, possess the *fixed* unilateral sighting faculty and handed-

[1] See the experimental studies of Baldwin, Nice, Woolley, Dearborn, and Major. Of the two heteronymous images the one belonging to the sighting eye is the only one that can be depended upon. In seven months the infant would discover this experimentally—would have to discover it, since any dependence on the false image would invariably be futile.

ness, developed originally as a result of man's activities as a weapon- and tool-maker. Arising in this way as the most advanced differentiation of the visual function, we are to look upon the unilateral sighting faculty as a mark of the very highest type of vision, a type that in the important matter of orientation at least is far superior to pure binocularity.

Traces of the more primitive fluctuating form of eyedness survive in the newer form's occasional failures and imperfections, as, for example, the persistence of the fainter of the two heteronymous images. To some persons this image appears very faint indeed; others see it almost as distinctly as the image of the sighting eye; still others—those with the best vision, paradoxically enough,—cannot see it at all. The degree of suppression, or success with which we ignore the useless and often confusing image, varies greatly with the individual—frequently varies even *in* the individual—and constitutes a factor of instability that speaks of functional changes still going on.

These double images are the glaring faults of pure or ideal binocular vision, since from the standpoint of the Cyclopean eye, or median reference plane, they invariably occupy false spatial positions. In actual life and work this proves so disadvantageous that for judging the position of objects seen indi-

rectly the median point of reference is never used; instead, as we have seen, we have a unilateral variation of pure binocularity that furnishes us with one image that is always dependable.

The somewhat widespread confusion of thought in regard to double images is due to the basic misconception alluded to in a previous chapter, namely, the supposition that the somatic direction-line is a median line, determined conjointly and equally by both eyes. The error here is an old and persistent one. We have demonstrated in our study of handedness that as a general rule the direction-line is entirely unilateral—dextro-lateral in the case of righthanded persons, sinistro-lateral in the case of lefthanded. The only exceptions are those rare fluctuating cases in which it is not partial to either side. With the aid of the manuscope so great a weight of confirmatory evidence has been secured for this explanation of handedness as to leave no doubt of the truth of these fundamental assertions.

It may be conceded that this inquiry solves the mystery that has always enshrouded man's preferential use of one hand. Does it leave a mystery of eyedness? Not if we look upon righteyedness, which characterizes the greater number of persons, as a Mendelian dominant, and upon lefteyedness as a simple recessive character. We have the testimony of Van Biervliet to show that in the great majority

of cases the right eye excels the left in acuity by as much as one-ninth. Gould states that a mathematically perfect pair of eyes does not exist, and that "as a large rule, the right eye is more nearly perfect than the left." Much similar testimony could be adduced tending to show that natural selection has been at work evolving a superior eye on the preferred side of the body. That such malformations and abnormalities as irideremia, ectopia of the lens, ptosis, some forms of cataract, albinism, the early development of *arcus senilis,* and other deviations from ocular standards are frequently transmitted in the line of descent is beyond all question. On the other hand, modifications and peculiarities of structure which are of service to the organism are likewise transmitted, natural selection acting in the long run to exclude the faulty and harmful variations and preserve those which are beneficial.

At the early period of infancy when eyedness first asserts itself, it seems not unreasonable to suppose that if there is any morphological or functional difference in the two eyes, the monocular sighting faculty will automatically or otherwise devolve upon whichever eye is the more efficient visually. If there is no appreciable difference, either an arbitrary choice will be made, or else the fluctuating type of eyedness results.

While there are interesting details that might be

elaborated, we believe that no further general explanation of the theory of unilateral sighting as the cause of handedness is necessary. The problems that require further experimentation and study have been indicated. Doubtless they will be taken up in future investigations. For the present it suffices us to know that with most of us fixed unilateral sighting is the rule, and right- or lefthandedness,—because of ease, rapidity, and sureness of movement, economy of muscular effort, and consequent all-round effectiveness of action,—the natural and inevitable result.

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